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GUIDELINES FOR DEVELOPMENT OF PROGRAMS IN SCIENCE INSTRUCTION, REPORT OF A STUDY, MAKING SPECIFIC REFERENCE TO THE TEACHING FUNCTION OF THE LABORATORY IN SECONDARY SCHOOL SCIENCE PROGRAM.

NATIONAL ACADEMY OF SCIENCES-NATIONAL RES. COUNCIL

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A DISCUSSION OF THE GENERAL PHILOSOPHY AND PRINCIPLES OF SCIENCE EDUCATION WITH PARTICULAR REFERENCE TO LABORATORY WORK AND SUGGESTIONS FOR THE IMPROVEMENT OF SCIENCE TEACHING ARE PRESENTED. THE DISCUSSION OF GENERAL PRINCIPLES INCLUDES SUCH TOPICS AS (1) THE PURPOSE OF THE LABORATORY IN SCIENCE TEACHING, (2) THE NATURE OF THE CURRENT SCIENTIFIC ENDEAVOR, (3) LEARNING THEORY AND ITS IMPLICATIONS FOR LABORATORY STUDY, (4) STUDENT TRAITS, (5) THE PREPARATION OF TEACHERS, (6) THE PHYSICAL PLANT AND FACILITIES, AND (7) RECENT EXPERIMENTAL APPROACHES TO THE SECONDARY SCHOOL SCIENCE CURRICULUM. SUGGESTIONS RELATED TO THE TEACHING OF SCIENCE ARE OFFERED FOR THE SAME TOPICS. APPENDIXES IN THIS WORK INCLUDE COURSE TOPICS AND ANNOTATED FILM LISTS FOR PSSC PHYSICS, BSCS BIOLOGY, CBA CHEMISTRY, AND CHEMS CHEMISTRY. A LIST OF GENERAL REFERENCES IS ALSO INCLUDED. (RS)

GUIDELINES FOR DEVELOPMENT OF PROGRAMS IN SCIENCE INSTRUCTION

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL

GUIDELINES FOR DEVELOPMENT OF PROGRAMS IN SCIENCE INSTRUCTION

Report of a Study, Making Specific Reference to the Teaching Function of the Laboratory in Secondary School Science Programs

Office of Scientific Personnel
National Academy of Sciences
National Research Council

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FOREWORD

During the past decade, countries throughout the world have evidenced increasing interest in science education in the public schools. This report by the Office of Scientific Personnel of the National Academy of Sciences—National Research Council examines the general philosophy and principles of science education with particular reference to use of the laboratory, and offers suggestions for application of these principles in the planning of secondary school science programs both in the United States and in areas of the world less technologically advanced.

Recognizing that no single set of equipment or specifications for facilities will serve all countries and all regions equally well, the report reviews the fundamental principles of program development and demonstrates the vital role of the laboratory in strengthening science teaching.

It brings together the ideas of scientists who have visited South and Southeast Asian countries and of some who have been active in programs revitalizing science education in the United States.

An advisory committee was appointed, consisting of: Randall M. Whaley, Wayne State University (Chairman); Harold Coolidge, National Academy of Sciences—National Research Council; Bentley Glass, The Johns Hopkins University; Robert E. Henze, American Chemical Society; William C. Kelly, American Institute of Physics; Ellsworth S. Obourn, U. S. Office of Education; and William A. Wildhack, National Bureau of Standards. Charles L. Koelsche, University of Georgia, spent several weeks in South and Southeast Asia to provide additional background information. Francis E. Dart, University of Oregon, and Robert C. Stebbins, University of California at Berkeley, visited seven countries of South and Southeast Asia during January and February of 1963 to discuss a provisional draft of this report with scientists, science teachers, and educational officials in that area, whose comments were most helpful in clarifying a number of points in the manuscript. Assistance in assembling and drafting some of the materials of the report was provided by Ralph W. Lefler and Joseph D. Novak, both of Purdue University.

This report was prepared with the assistance of a grant from the Ford Foundation.

M. H. Trytten
Director
Office of Scientific Personnel

May, 1963

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INTRODUCTION & SUMMARY

Making recommendations for educational change is a hazardous undertaking. Certain elements or procedures may be suggested, however, which should be considered in planning new programs or in organizing new materials and courses. Detailed prescriptions designed to meet specific objectives at a particular time and place can result ultimately from such an approach. Success will depend in part on a frank and objective appraisal of problems. Desirable long-range goals will have to be broken down into a series of realizable intermediate objectives reached by effective matching of resources and needs. It is within this broad framework that the present report has been developed.

The report discusses the rationale for the laboratory as an integral and indispensable part of an effective course in science. This leads into a brief analysis of three basic elements to be considered in planning for the laboratory—namely, the student, the teacher, and the facilities and equipment. Finally, reference is made to some of the major curriculum projects which have in the past few years made significant changes in secondary school science in the United States. Objectives of these projects, examples of their work, and in particular their viewpoints and actions concerning the laboratory are reviewed.

The recommendations include some that are general, and that should be applicable wherever improvement in laboratory instruction is sought.

From the various detailed recommendations, the following were selected as basic elements in any plan for developing effective laboratory work as part of a science course.

1. The teacher is central. Neither good equipment nor excellent facilities will result in effective use of the laboratory if the teacher does not have an adequate understanding of the science and the essential role of the laboratory in science instruction.

Extraordinary effort should be directed toward revitalizing the education of new teachers, and devising special activities to help present teachers gain more insight into modern science and its dependence upon free inquiry exercised in laboratory work by students themselves.

2. Planning for new courses and for laboratory facilities and equipment must include detailed and continual participation by professional scientists from outside the school system. A successful course in science should help students acquire a view of science as an effective intellectual process of inquiry leading to a body of powerful and useful concepts. This cannot occur if the content and the approach do not reflect accurately both the current content of science and the way in which scientists constantly enlarge and revise our store of knowledge. Collaboration of professional scientists, educators, and teachers is imperative in all phases of planning for course content, laboratory facilities and equipment, and programs for teacher education.

3. Simple, well-designed, functional laboratory equipment may not be less expensive than complex apparatus, but it is always preferable.

4. Administrative mechanisms, educational activities for teachers, and investment in large-quantity manufacture of laboratory materials, should all reflect a fundamental decision that periodic reviews are essential. Scientists, science teachers, administrators, and educators should participate in these reviews. Science is perhaps the most dynamic of human endeavors. This must be acknowledged and reflected in the teaching of science. Flexibility to allow for pilot experiments, for new course materials, for use of various approaches to teaching should be built into the system.

5. It is very important to ensure that student examinations do not become an end in themselves. They should remain a means for maintaining minimum standards and they should always allow enough flexibility to make experiment and improvement possible. Ideally, the examination system should be so closely integrated with other aspects of teaching that it both provides for the experimental development of new content and new teaching methods and acts as an incentive toward adoption of tested improvements. Inflexible examinations tend to promote inflexibility in course content.

No single method should be relied upon to achieve the desired results. No particular sequence of steps will ensure success. Concurrent action for the improved training of teachers, participation of scientists, selection of equipment, flexibility of programs, and adjustments of syllabi and examinations should provide marked progress in science education.

I. SCIENCE EDUCATION AND THE ROLE OF THE LABORATORY

A. THE RATIONALE FOR THE LABORATORY

1. *The Purpose of the Laboratory*

We shall consider the laboratory portion of a course in its functional relation to the course as a whole. Out of function grows a description of what the laboratory should provide in equipment and facilities—the open field where nature can be observed; the room equipped with apparatus for conducting experiments and testing observations. We trust that it will become clear that the function has far more significance than the practical application of the lessons learned.

Alternative means, or preferably a combination of approaches, can be used to provide the student with opportunities for deepening his understanding of science through laboratory work. Experimentation may be conducted by individuals or groups of students, by demonstrations by the instructor, and in part by use of specially prepared films, slides, or film strips. Primary attention in this report will be directed to facilities and equipment intended for use by students themselves, singly or in groups.

One of the important functions of the laboratory is the deepening of a student's understanding that scientific and technological concepts and applications are closely related to his own natural environment.

The laboratory in a science course is concerned with a combination of facilities and techniques that will enable the student to observe natural phenomena with a discerning eye, to make measurements and analyze the data recorded, and to engage in free-ranging investigations that do not necessarily have a predetermined end. The value of these experiences will in large measure depend upon their relevance to the other portions of the course of instruction, to the functions they serve in the course, and to the objectives set for the course as a whole. It should be emphasized that the laboratory is an integral part of the course of instruction, related inherently to class discussions and text materials. Examinations should test for understanding and competence developed in laboratory experiments as well as for materials presented and discussed in other phases of instruction.

2. *The Nature of Contemporary Science*

Much of what has been justly criticized as inadequate or inappropriate instruction in science today, including laboratory work, results from a widespread misconception of the nature of science. Criticism of science education has been vigorous in recent years, with resulting massive programs for revitalization. The character of the changes under way in the United States, by way of example, and of the recommendations that are made later in this report can perhaps be better understood in the light of the significant evolution that has taken place in science as a method of inquiry, while it has continued its growth as a body of knowledge about life processes, matter, and energy in our universe.

No longer the relatively passive occupation of a few individuals recording and classifying their observations of nature, science has become a powerful process of inquiry, making possible the searching out, identification, and solution of diverse and complex problems.

The nature of science today is perhaps more sharply revealed if compared with its earlier phases. The great Greek philosophers were also systematic observers of natural phenomena. Unfortunately, the interpretations of nature stated by Plato, Aristotle, and others were accepted unconditionally in the Middle Ages as irrefutable law. Science became merely an extended search for more absolute truths. Once arrived at, such absolute truths were endowed with an aura of authority which inhibited and even literally blocked free and searching inquiry for centuries.

Not until the sixteenth century did the irrepressible curiosity and skepticism of Galileo make a break with authoritarian science and open the flood gates to new experimentation. Newton, Priestley, Linnaeus, Darwin, Maxwell, and many others followed, deriving new laws that stood on a foundation of objective observation and analysis. So successful was experimental science in the next 300 years that a comfortable notion evolved that all nature in principle was run like a well-oiled machine, with a set of basic, understandable laws to explain operations and relationships.

This heritage profoundly influenced science education, particularly laboratory work as part of a course. Essentially, laboratory assignments became merely exercises to verify laws or rules.

Alternatively, the laboratory was viewed by others as showing the practical side of science, divorced from and having less prestige than the theoretical or, by implication, "impractical" parts of the course.

Science courses demonstrating the validity of well-established laws without giving evidence of continual evolution and growth cannot help but lose contact with new concepts coming out of research laboratories and out of the intellectual struggles of theorists. Also, this approach fails to develop in students the sense of excitement that comes from discovery, from distilling out of independent measurements the common elements which make up a new generalization and perhaps ultimately a new theory.

Contemporary science, if adequately and honestly portrayed in courses of instruction, demands much of the laboratory, for science of the twentieth century is a dynamic enterprise that flourishes because new questions are asked and new leads sought in experimentation. Sometimes the information obtained results in drastic modifications of previous theories or generalizations. Significantly, in this century science is not thought of as resting on a body of absolute truths or laws, but rather on an acceptance of a degree of probability or of approximation in our interpretation of phenomena and our descriptions of relationships. Although the special and general theories of relativity, quantum theory, the uncertainty principle, and the nature of gene-change proved to be giant steps forward in our comprehension of macroscopic and microscopic phenomena, they also injected a new understanding of boundary conditions for the applicability of laws and theories. They underscore the essential dependence of science, as a continually evolving enterprise of the human mind, upon careful experimentation, upon more and more sophisticated work in the laboratory. The laboratory, in all its variable forms, is thus essential for future developments in science. It should be so represented, as an integral part of instruction in science.

In the laboratory the student can be taught more readily to be discriminating in observation, to evaluate evidence or data, and to sense the importance of care and skill in the taking of measurements.

In the laboratory the student should develop the contemporary view of the limitations of measurement, of inherent uncertainty, of the possibility of achieving only better approximations to what will ultimately be accepted as most likely values. But with this must be coupled an appreciation for the continuing utility of such measurements, because one can know the limits of their applicability or of their exactness. Similarly, the continuing usefulness of certain scientific "laws" can be demonstrated through application even if they fail to account for all phenomena, for example, in the microscopic domain.

3. *Implications for the Laboratory from Studies on Learning Processes*

The role of the laboratory and its potential for contributions to science education can, in part, be clarified by reference to a few findings from research on learning processes.

Research in the last half century has refined the concept of transfer of training and shown that it applies only within related fields. The widespread use of mock-ups in electronics and Link trainers in aviation is based on the fact that skills and understanding gained from model systems can be transferred effectively to actual practice in full-scale operations. The laboratory can provide students with an understanding of procedures for scientific investigation, including control of certain variables, careful observation and recording of data, and the development of conclusions. In essence, the study of science through laboratory experience serves a dual function. The student learns the concepts and facts of the science itself and, in addition, learns how to grow in his knowledge and understanding of science.

Of more significance, however, for the planning of laboratory work are results of classroom experiments conducted over the last fifty years. These deal with the concepts of *readiness, motivation,* and *structure.* They have application for the teaching of science at all grade and age levels; they deal both with the nature and organization of the material to be taught and with the procedures for effective learning.

Concerning readiness of a pupil to learn, Bruner has written:

> *We begin with the hypothesis that any subject can be taught effectively in some intellectually honest form to any child at any stage of development. It is a bold hypothesis and an essential one in thinking about the nature of a curriculum. No evidence exists to contradict it; considerable evidence is being amassed that supports it.*

. . . Research on the intellectual development of the child highlights the fact that at each stage of development the child has a characteristic way of viewing the world and explaining it to himself. The task of teaching a subject to a child at any particular age is one of representing the structure of that subject in terms of the child's way of viewing things. The task can be thought of as one of translation. The general hypothesis that has just been stated is premised on the considered judgment that any idea can be represented honestly and usefully in the thought forms of children of school age, and that these first representations can later be made more powerful and precise the more easily by virtue of this early learning.[1]

Differences in environment and experience are to be found even for children in the same family. The differences are much greater between children of different families or communities, and enormously greater for different countries and cultures. The central problem, therefore, is that of determining course content and procedures which will effectively match the student's present capabilities with his potential for conceptualization of ideas.

Most children are ready to modify, enlarge, and deepen their concepts of matter, energy, living, etc. The task of the teacher and the curriculum developer is to determine what kinds of experiences (emotional as well as cognitive or intellectual) are appropriate for a specific child or group of children at a given time and place.

By way of illustration, consider a variety of treatments for the important concept of energy utilization by living things. Children can soon identify eating as related to vitality, energy, ability to run, play, and perhaps to work. The relationship of eating to compound synthesis and thus to growth and maintenance of the body is more subtle. Children who have suffered or are suffering from insufficient caloric intake may understand the relationship of food to body energy. It may be more difficult to illustrate that plants require energy, though experiments can be conducted with seeds from which some or all of the stored food has been removed. If microscopes are available and students have sufficient manipulative skill to use them (perhaps nine years old or older), capture

[1] Numbered references refer to a list of references on page 43.

of food by protozoans, formation of starch granules in leaf cells, and similar observations can extend the range of experience demonstrating the energy requirement of all living things. As this idea is developed, one can also enlarge on the child's experiences to illustrate specific utilization of certain foods, such as vitamins. Application of this can be studied in relation to maintenance of a healthy person, cow, or bacterial cell—the brick and mortar experiences for structuring the idea or concept of homeostasis.

Fundamentally, work in the laboratory, to have meaning and to be effective, must take into account differences in level of student development, environment, and experience.

Of equal or perhaps even greater concern is the psychological problem of arousing in the pupil a desire to participate, to learn. This is the problem of *motivation.*

> *Somewhere between apathy and wild excitement, there is an optimum level of aroused attention that is ideal for classroom activity. What is that level? Frenzied activity fostered by the competitive project may leave no pause for reflection, for evaluation, for generalization; while excessive orderliness with each student waiting passively for his turn, produces boredom and ultimate apathy. There is a day-to-day problem here of great significance. Short-run arousal of interest is not the same as the long-term establishment of interests in the broader sense. Films, audio-visual aids, and other such devices may have the effect of catching attention. In the long run, they may produce a passive person waiting for some curtain to go up to arouse him.*[2]

Among the important concerns in motivating students to learn is the apparently autocatalytic nature of learning. An emotionally satisfying, successful learning experience is one of the strongest incentives for continued learning. It is here that the laboratory holds great potential. A pupil who discovers that an electric current in a wire around an iron core can induce a magnetic field in the core, and conversely that a moving magnetic field can induce an electric current in a surrounding wire, has grasped an important relationship between electricity and magnetism. If the *discovery* was made with the student maneuvering the coils, magnets, and meters, it is likely that he experienced considerable emotional satisfaction *during* the learning, especially as the idea crystallized in his mind. This student is likely to be *motivated* toward learning more about magnetic fields, electron movement, etc. The problem, then, is to provide initial laboratory experiences (or to build on previous experiences) which do result in student involvement in an emotionally and intellectually satisfying manner.

It should be stressed that this approach is almost the antithesis of much conventional science instruction. Students learn "the right-hand rule," not as a result of experiences with coils and magnets, but as a "law" to be memorized for the next examination. It is very improbable that this kind of "learning" will be autocatalytic! Much of what follows in this report is an attempt to suggest ways of involving students in learning science which can increase their *intrinsic* desire to learn (as contrasted with the *extrinsic* motivation supplied by examinations and competition). The major problem in science teaching is to find ways to present opportunities for pupils to learn important facts, principles, and major ideas in science; it is not to find more intricate and demanding examinations and to set these as primary motivators.

Establishing the role of the laboratory in the science program involves not only knowledge of *how* the material should be presented for maximum effective learning, but also *what* the students should learn. The content of science courses has failed to keep pace with the enormous advance in the sciences over the past two or three decades. In most schools, physics has been presented without the suggestion that quantum theory has been developed; chemistry is taught as though the mechanism of bonding were never studied, and biology courses frequently omit the nature of genes and gene action. This lag between science teaching and the frontier work in science is a legitimate concern, and is largely the reason that there are now in the United States several important groups of scientists, educators, and teachers engaged in the process of defining what we should teach in secondary schools.

It has been the common concern of these groups in the several sciences that students, in addition to learning the concepts of science, should learn the processes by which scientific concepts were evolved and enlarged.

Concepts may be regarded as complexes of cognitive, factual information, laced together by experience in problem solving, and overlaid with substantial emotional involvement. These components—the facts, experience with analysis and solution of problems, and a sense of emotional excitement—seem to be essential ingredients for a school science program if concept development is to occur even to a moderate extent.

Such elements are present in the work of a practicing scientist. It is of some significance to conclude from studies on concept development that an effective approach to science education would be to involve the student as much as possible in the procedures followed by a scientist at work, to give the student some insight into the methodology of scientific inquiry, of the acquisition and interpretation of data, and of the sense of excitement that comes from discovery.

B. ESSENTIAL ELEMENTS OF A PROGRAM OF LABORATORY SCIENCE INSTRUCTION

1. *The Student*

Children are often described as being the same the world over. This is true in part. They play, mimic adults, and are concerned with their own affairs and development relative to others. This similarity, however, does not mean that identical programs of education would likely produce on the average comparable results with different groups of young people. There are differences growing out of the variety of stages of technological advance to be found among different countries of the world, or within a single country or region. A student's ability to understand a demonstration, a discussion, or an experiment will in part reflect his prior familiarity with the materials, the devices, or the general utility of the scientific fact.

The scientific sophistication of a group of students can be assessed through knowledge of their home environment, the mores of their community, and the availability and use of various means of acquiring information—films, radio, television, books, magazines, and newspapers.

In regions where economic and technological advance is rapid, young people are most likely to respond quickly to change—another reason for continual review of the science curriculum. The content of the science course and laboratory should not move too far ahead of the technology of the region, but it is equally a mistake not to reform and rebuild the curriculum to acknowledge external changes as they occur.

2. *The Preparation of Teachers*

a. Education

For hundreds of years men have sought to determine what makes a good teacher. Are teachers simply born with the personal qualities needed, or can an educational program effectively develop the knowledge, the skill, and the personal attributes that somehow are blended in the person of a good or superior teacher?

Over the past half century or so, teacher education in the United States and in many other countries has been based on the defensible premise that good teaching involves more than knowledge of the subject taught. An unfortunate division of responsibility resulted from the attempt to introduce methodology into teacher training. The teacher aspirant was expected to acquire in a very few courses sufficient knowledge and understanding of the subject as taught in a traditional-subject department, while he learned methods of teaching, even of organizing the subject itself for classroom presentation, in courses given by professors of education.

This pattern has proved disastrous in science education because it separated the professional scientist from the professional educator. Those most knowledgeable and concerned about the science itself paid little or no attention to the legitimate problems of prospective teachers of the subject. Those responsible for education as a profession gradually shouldered major responsibility for planning teacher education programs and objectives, leading to an overemphasis on methods of teaching at the expense of studies in science. Under such circumstances it has taken an unusually perceptive and skillful person to develop an exciting and challenging approach of his own to teaching, based on sound knowledge of the content and process of science. The fact that such teachers so seldom appear has been a cause of grave concern to both scientists and professional educators.

The most promising move to improve teacher education has been to restore once more the feeling of common concern and responsibility between scholars in science and professors of education for developing teachers of quality and competence. Constructive scrutiny and active participation by scientists in seeking improvements in programs of teacher education are already having marked effects on the preparation of secondary school teachers. The vehicle by which this renewed collaboration is being forwarded most effectively in the United States is complete reappraisal of the science curriculum, primarily for the secondary schools. This forces changes in the teaching of science at the college level, since (1) secondary teachers will reflect in their teaching the concepts and methods by which they were taught, and (2) high school graduates will ultimately demand college courses geared to their higher levels of achievement and sophistication.

Planners of university science courses designed to prepare secondary school teachers must recognize that the teacher may need to use relatively modest laboratory facilities and equipment in reaching his objectives. No single or presumably unique approach should be emphasized to the exclusion of other possibilities. The ability to improvise, to adapt, or to alter the level of sophistication of laboratory work must be derived from a thorough understanding of the material to be studied and of the nature of the science to be taught.

To illustrate, consider again the example from biology discussed earlier—the concept of energy utilization. The teacher in a region where facilities are minimal should be familiar with techniques for demonstrating that pea seedlings will survive for a shorter time with no cotyledons than with one or both cotyledons.

Parallel experiments might be suggested to the students from which a generalization may develop, e.g., stored food provides the sustenance for germination and early plant growth. Further exploration of factors affecting seed viability may stem from this topic, leading to an understanding of grain and seed storage problems, and acceptance of the agricultural consultant's recommendations for seeding at sufficient depth to avoid drying, but not so deep as to inter the seeds permanently.

This same energy concept can be treated with more sophistication where relatively elaborate equipment such as a centrifuge is available. An experiment might include procedures of extracting chlorophyll from plants with chromatographic separation, demonstrating that chlorophyll can capture energy from only certain colors or wavelengths of light. The suggestion might be made that, potentially, a physical system utilizing essentially all the energy of the solar spectrum might prove to be a better energy source for man than photosynthetic products, at least where other energy sources are limited.

Both experiments help develop concepts regarding energy storage; both are appropriate for secondary school students. Selection from alternative approaches would be determined by the availability of resources and the appropriateness to the cultural level of the community.

b. *Continued Professional Development*

Continuous changes in the needs and character of their communities and rapid and significant advances within science itself require that teachers of science actively continue their reassessment of what and how they teach. The significant scientific knowledge of the world is estimated to be doubling approximately every twelve to fifteen years. The textbooks and other new materials prepared by the science curriculum studies will have to undergo a thorough revision within less than five years from the time of their publication. How long, then, can we expect teachers of science, who have large classes and innumerable educational obligations, to keep their fund of knowledge and the content of their courses up to date? It seems obvious that a radically new educational approach is needed if our schools and their curricula are to keep pace with the scientific, technological, and cultural development of the world.

Many efforts have been initiated with this end in view: summer science institutes, academic year and in-service institutes, refresher courses for the teacher. All these efforts seem inadequate to meet the need. The voluntary attendance of teachers at summer science institutes, supported by the National Science Foundation and developed on a larger scale than any other measures aimed in this direction, tend to reach a relatively small proportion of the teachers. Moreover, they do not reach those teachers who most desperately need assistance, since the applicants who are accepted are usually those with the highest qualifications.

Perhaps a time will come when science teachers will have regular leaves of absence for a year or half a year, at intervals of four to six years, to be spent in re-education and re-preparation for their professional needs. Such a plan would meet with success, however, only if governments would provide funds for the maintenance of teachers during their sabbatical years. In the face of great shortages of science teachers at the present time, it may be wondered whether the requirement, under this plan, for an additional recruitment of perhaps 20 per cent more science teachers than now exist would not present an insuperable difficulty. On the other hand, the much more attractive character of a teaching career under the suggested plan would perhaps aid greatly in the problem of recruitment of teachers.

In one country, Japan, very considerable steps in this direction have already been initiated. Seminars for science education are being started with the objective of retraining one-tenth of all elementary school teachers and one-half of all secondary school science teachers in five years, and special science education research laboratories are being started in about thirty national universities, where science teachers can be brought into close contact with active scientific research and can gain deeper insight into the nature and spirit of scientific investigation. Most radical is the plan to develop "Science Education Centers" in each of the prefectures throughout the country. Eleven such centers are already in operation and eight more are currently under construction. Here specialized leaders in science will work in conjunction with the universities and the Board of Education in the retraining of science teachers. Retraining at the centers will be mandatory for scheduled groups of teachers, but, in addition, teachers may attend more frequently on a voluntary basis.

The matter of prime importance in all such programs is the development of mechanisms to keep secondary school teachers, elementary teachers, and active university scientists in close and continuous communication. Advances in our understanding of how people learn and by what techniques they may best be taught may be fruitfully introduced in the retraining program, too; but the greatest benefit will flow from the break-down of the barriers that have unfortunately grown up between the teachers of science, on the one hand, and the practitioners of science, the research workers, on the other.

3. The Physical Plant and Facilities

a. General Remarks

It should be emphasized again that a preoccupation with the material and physical elements of a building or with the equipment of a laboratory will not guarantee effective learning. The attitude, the understanding, the knowledge, and the motivation of the teacher are central. However, even the best teacher must have facilities and equipment to teach effectively.

School buildings should be planned to provide talented teachers with the best instructional resources that can be made available.

Laboratory apparatus can be selected to reflect different levels of economic resources and still provide essential opportunities for students to learn what can best be learned by direct experimentation and exploration in the laboratory. Apparatus, materials, and equipment should be selected because of their relevance to the course, to the function they serve in developing concepts and an understanding of the process of scientific inquiry, and to their value in motivating students to want to learn. Relatively simple equipment, though not always less expensive, is usually more effective than complicated technical devices. Common sense should dictate a proper balance between expenditures for relatively inexpensive pieces which open the way for individual student participation, and for a few expensive pieces which enable interested and able students to delve more deeply into some experiments.

In general, most experiments can be performed with relatively inexpensive equipment. However, a teacher using minimal equipment needs to exercise great ingenuity in supplementing laboratory facilities. For example, extensions and discussions of observations that can be made only with a microscope providing adequate magnification give the student some appreciation and understanding of the relation of structure to function. The level of sophistication to which this comprehension can rise is to some degree dependent on the quality and power of the instruments at hand for student use. The adequacy of the equipment as well as the scope of the laboratory can be extended by the use of slides and films. With a background of some student experimentation, visual aids can be used to bring new materials into view. However, appreciation of the significance of measurements or demonstrations presented in such fashion can be very limited unless there has been actual student participation in other, less difficult experiments.

It should be recognized that the compound microscope has certain limitations. For many purposes a low-power stereoscopic (dissecting) microscope is more useful. Schools should try to divide their purchases between the two types.

b. Guidelines

The following suggestions are listed not in order of importance, but in accordance with the order in which they might be considered in planning. Some may appear to be obvious, and applicable to schools generally, but they are included to make clear that no unique arrangement or set of specifications is required. Effective work can be organized with a minimum of facilities.

(1) *Location.* Consider possible need for expansion; is space available? Are services such as power, light, heat, water, and sewer at hand?

(2) *Cooperative planning.* Classroom teachers, architects, and school administrative personnel should cooperate in planning the laboratories and their relation to other parts of the building. A scientist or science teacher who had recently participated in science curriculum studies would be of valuable assistance to ensure that new laboratories contain the elements most appropriate to the present functional view of the laboratory.

(3) *Laboratory space.* As available resources vary considerably from one part of the United States to another, and from country to country, the degree to which the laboratory can be developed depends upon local circumstances. The best available working space and facilities should be provided.

Possible future expansion should be considered in current planning. Adequate light, ventilation, and heat if needed, are fundamental. Locked space—a room or cabinets—is necessary for the storage of apparatus when not in use. Work tables, either fixed or movable, should be provided. More detailed suggestions appear in Chapter II.

(4) *Special aids to teaching.* In addition to blackboards, laboratory manuals, and reference books, each laboratory should provide for circuits, a screen, darkened windows, or other necessary facilities for using films, film strips, and slides.

(5) *Relation to science course objectives and school procedures.* The interrelationships of the laboratory with other portions of the science course should be continuously correlated. Special care should be taken to ensure that the examinations measure accomplishment in the laboratory as well as factual material learned from texts and discussion. The relation of the laboratory to the scheduling practices of the school must be considered. Scheduling, lack of free time of students, laboratory periods that are too short, and inaccessibility of the facilities after hours will bear directly on

the degree of success achieved even with a well-organized laboratory facility.

c. Possible Future Trends

The present pattern of classes of uniform size has led to a standardized building composed of multiples of nearly uniform rooms. Principal objections to this pattern are:

(1) A class of 30 or more students is too large for free discussion, yet it is smaller than need be for effective presentations by lecture or demonstration.

(2) The use of lectures by special resource teachers, films, or even television where available may be made before large groups, allowing teachers more time for small group discussion and for small group or independent laboratory work. A school building planned for such scheduling will necessarily differ from the conventional grouping of classrooms and laboratories of essentially the same size and appearance.

(3) Independent student study and activities require work space and facilities not found in conventional classrooms. Much worthwhile activity must now be assigned as homework, even though conditions in the home may not be conducive nor guidance easily available.

(4) A teacher's student-contact time is fixed by traditional buildings at approximately 125 student-contact hours per day, with almost no time available for study and preparation of new material. Providing for instruction in various-sized groups might develop a more flexible schedule, allowing an individual teacher or a school to make more effective use of time and facilities.

(5) Experimentation with curriculum and classroom practices is handicapped by a building of rooms designed for classes of equal size since hypotheses must be structured to fit available space and time.

With a wide array of objections regarding the present 25-35 student classroom unit, it is somewhat surprising that this pattern continues. It should be noted, however, that the present secondary school pattern in the United States *does not* continue in most colleges.

We recommend that the planning of secondary school facilities include a careful analysis of a wide variety of instructional needs. Even if no dominant stereotype is developed, new school buildings in the United States will probably include some of the following:

(1) An auditorium or large assembly room for instructional use as well as for general meetings of the student body.

(2) Smaller auditoriums or large classrooms for 70-150 students, equipped for the use of visual aids.

(3) Seminar or discussion rooms for 8-15 students each.

(4) Study and/or work areas for 1 or 2 students per area. Such areas for laboratory work in science would differ from those used for language study.

(5) Adequate library space, including facilities for branch libraries in classrooms.

C. RECENT EXPERIMENTAL APPROACHES TO THE SCIENCE CURRICULUM AT THE SECONDARY LEVEL IN THE UNITED STATES

Over the past twenty years, the public has evidenced a growing uneasiness regarding science teaching in the United States. Most of the early concern was on the *quantity* of science taught, but recently criticism by scientists, secondary school teachers, and lay leaders has focused on its *interpretation*. Science instruction has emphasized the *products* of science with little or no attention to its *processes* or to the nature of the inquiry that results in scientific advance. Equally disconcerting, the content of many courses was largely obsolete, important new advances being treated as an "extra chapter" rather than integrated into the total course structure.

The aroused but independent concern of many individuals, with support from foundation and private sources, brought about the initiation of several programs for the improvement of physics, chemistry, and biology teaching at the secondary level. Substantial funding by the National Science Foundation has made possible the development of several comprehensive programs in the sciences. The common feature of all these programs is their direction by university scientists having knowledge and experience in a growing field of contemporary science, and their involvement of professional educators and science teachers.

During the period, 1956-1959, several groups were organized for the purpose of reviewing the status of secondary school science curricula. Four of the groups that have received National Science Foundation and other support are:

The Physical Science Study Committee (PSSC)
The Chemical Bond Approach Group (CBA)
The Chemical Education Materials Study Committee (CHEM)
The Biological Sciences Curriculum Study (BSCS)

Each of these groups recognized that incorporating important advances in the sciences into secondary school instruction required new textbooks, laboratory guides, supplementary readings, and visual aids. A review of the developments of these groups in physics, chemistry, and biology illustrates the kinds of curriculum problems the groups met. Comparable activity is under way in mathematics.

The selection of these four groups for detailed discussion in no way minimizes the importance of other new programs that have been developed in the last decade, such as the excellent set of film lectures in physics prepared for secondary school use by Professor Harvey White of the University of California.[3] This particular film was designed to assist teachers and, in emergencies, to fill instructional needs where teachers and facilities were not available. Some similar films, produced within the country of use, might be found useful in educating teachers and supplementing science instruction. Materials on other new courses are listed in Appendix E.

1. *Physics*

For years, physicists in the United States have been uneasy about the state of secondary school physics teaching, about the caliber of teachers, and their training, and about the materials contained in texts and laboratory manuals. Careful analysis of many texts, films, and classes in physics provided the conclusion that little twentieth century physics was portrayed satisfactorily in the secondary school course. As mentioned earlier in this report, science has moved far beyond the stage of a search for absolute laws; leading to the contemporary view of the physicist which must include quantum theory and wave mechanics, probabilities instead of certainties, and a recognition that the process of science is an open-ended search best taught by allowing the student to participate in the search.

In the summer of 1956, a group of physicists met at the Massachusetts

Institute of Technology to plan a program of action. With support from the National Science Foundation, the Physical Science Study Committee (PSSC), under the chairmanship of Professor Jerrold R. Zacharias, was created.

The Committee found that textbooks in general were outdated, and that those that attempted to incorporate new developments and an increased emphasis on technology acquired a patchwork quality as well as an increasing mass of material too large to be covered adequately in a school year.

From the beginning the group intended to prepare a new and integrated program, based on a new textbook, laboratory manual, experimental equipment, films, and supplementary reading materials. They planned to present physics in a logical fashion, leading to formation of concepts that develop the unity of science, and at the same time, to treat the subject as a significant intellectual and cultural activity having value transcending the technological alone.[4]

In the preface to the PSSC text,[5] Dr. James R. Killian writes:

> *Throughout, the student is led to realize that physics is a single subject of study. In particular, time, space, and matter cannot be separated. Furthermore, he sees that physics is a developing subject, and that this development is the imaginative work of men and women like him.*

The laboratory performs a critically important function in the course. The experiments cover 50 topical areas and have necessitated the development of new equipment and guide books as required to meet the objectives set. In the 1959 Progress Report,[6] the Committee wrote:

> *Even more than the text, the laboratory program emphasizes student participation in the development of concepts. Students study natural phenomena in situations which they create with their own hands. Laboratory work plays an important role as a means of exploring a field before formal definitions or laws are introduced. Here, students learn to face questions without answers being immediately available.*
>
> *In designing experiments for the laboratory program, the Committee has been guided by the following objectives:*

1. *Experiments should be true experiments and not routine accumulation of data to agree with a result well known in advance;*
2. *Experiments should be performed, wherever possible, with simple apparatus that can be quickly assembled by the student;*
3. *Experiments should encourage further work along suggested lines and should lead to the consideration of theoretical ideas growing from the experiment;*
4. *Experiments should be guided by the ideas already developed.*

The descriptive material accompanying each experiment attempts to open doors for the student, without leading him step by step to an inevitable conclusion or generalization. Prescriptions are avoided. The old pattern of experiment by filling in blank spaces or numbers into an equation is gone.

Clearily, there are some demonstrations or experiments which would add much to the value of an introductory course at the secondary school level, but which cannot be performed because the equipment is expensive or generally unavailable. Films in the PSSC program fill this need, allowing students everywhere to benefit from carefully prepared demonstrations.

Reading the table of contents of the PSSC Laboratory guide (Appendix A-1) or a list of PSSC films (Appendix A-2) will not make obvious the differences between the PSSC approach and that which it is replacing. For example, Chapters 20, 21, 22, and 23 of the PSSC textbook are entitled, respectively: "Newton's Law of Motion"; "Motion at the Earth's Surface"; "Universal Gravitation and the Solar System"; and "Momentum and the Conservation of Momentum." These titles are not really different from what might be found in a conventional text. The difference lies in the organization for development of ideas. To illustrate, the following is taken from page 327 of the chapter on "Motion at the Earth's Surface":

When we remove the air, we find that all objects, regardless of shape or density, fall with the same acceleration at a particular position near the earth's surface. Furthermore, *because g does not change direction or magnitude appreciably unless we move through distances comparable with the size of the earth, the acceleration is closely the same for objects falling anywhere within a room, within a building, a city, or even a state.*

The words underlined in this quotation are what distinguish this material, and others like it, from what would be found in most other texts.

The importance of relating theory to experimental observation and the laboratory is repeatedly brought out in the text. On page 268, the chapter on "Waves and Light" says:

Our study of refraction and dispersion clearly shows that the wave picture of light succeeds where the corpuscular picture fails. Yet the corpuscular picture predicts correctly that light should propagate in straight lines and cast sharp shadows. Can a wave model also account for these properties of light?

This is followed by experimental illustrations, including laboratory work in which a ripple tank is used to demonstrate some properties of water waves which have implications for the behavior of light.

The experience of those responsible for planning and trying out the PSSC material lends support to the proposition that the laboratory must be an integral, and perhaps the most important, part of a course in science at the secondary school level. Further, the experiments should be simple in material and equipment requirements, but sophisticated in design to allow students to sense the excitement of discovery.

2. *Chemistry*

Reviewing the steps that led several chemists and teachers to conclude that a radical revision in the content and approach to the teaching of chemistry was long overdue at the secondary school level, would show findings essentially parallel to those of biologists, physicists, and mathematicians. The content of courses and the approach to teaching chemistry simply did not reflect the present state of knowledge or understanding of scientists active in research and advanced studies. Emphasis on memorization of facts, formulas, processes, and compounds not only failed in the typical secondary school course to develop the unifying concepts that lace the science together, but they did not generate in the student a feeling for science as a continuing and open-ended search.

One of the unifying concepts in modern chemistry is that of the nature of the bond that binds atoms together into compounds of various kinds and characteristics. This bond was, for a long time, merely indicated by a line or lines between the symbols for the chemical elements, but the nature of the force or bonding mechanism was completely obscure. With the advent of quantum theory and wave mechanics in physics, great strides were made in establishing a useful working hypothesis concerning the movement of electrons around the atoms and their role in providing the chemical bond between atoms.

Several chemists considered this unifying concept as one around which an effective and stimulating course in chemistry could be built. In response to a specific suggestion by Strong and Wilson in 1958,[7] the National Science Foundation made a grant to a group which subsequently became known as the Chemical Bond Approach (CBA) group. The underlying convictions and objectives of these chemists and teachers are indicated in the CBA Newsletter for February 1961:

> *If there is any one characteristic of the basis for CBA Chemistry, it is probably the belief that chemistry is inherently fascinating and that this fascination can be seen by students early in their exposure to the subject. To reveal the fascination, it is not enough, however, to have the student memorize the data of chemistry. Indeed, we would argue that chemistry is more than the facts which make up the information possessed by chemists. Rather, chemistry as practiced is a powerful process for uncovering and extending natural phenomena. The power resides in the combination of ideas and facts or of concepts and experiments. As the student finds himself able to participate in the process, he also finds fascination.*

Of particular relevance to the concerns of this report is what the group has to say about laboratory work by students. To continue with the above quotation:

The course, then, is organized to aid the student in his study of the interaction of conceptual schemes with observation and experiment. Perhaps the best part of the course in which to see this is the laboratory work. Successful laboratory work in the CBA program means that the student not only collects data in the laboratory, but he also applies ideas to his data. The laboratory experiments are presented as problems to be explored or, if you wish, as puzzles to be solved. Insofar as possible, it is left to the student to decide what information he needs to solve the problem. Ideally, some information should come from the laboratory and some from the literature. These are fitted into a logical scheme based on a set of assumptions and often some mental model. Logical reasoning leads to a reasonable solution to the problem. In most cases, either the solution to the problem or some of the difficulties will suggest still other paths to be explored. Where time and facilities permit, the student is encouraged to follow up such "extensions" as may intrigue him. A good many students seem to get real satisfaction out of such further explorations . . . In such a setting, it is important to note that laboratory experiments do not automatically lead to a predetermined result known only to the teacher. It is the ability of the student to follow and even to construct a line of argument that is the hallmark of good work . . . Our main criteria for an effective laboratory experiment are: it should be fitted tightly into the text so that it makes an important contribution to the pattern of the course; it must involve both the acquisition of data by the student and the execution of a logical argument, and it should become one of the threads in the course which contributes to at least a few subsequent discussions.

As with the materials for the physics course, extensive trials in secondary schools across the United States were carried out, and revisions in the texts and experiments suggested.

The Laboratory Manual Table of Contents is reproduced as Appendix B.

A second group of chemists, also with support from the National Science Foundation, began work early in 1960 to design a somewhat different set of materials for high school use. This second group, which became known as the Chemical Education Material Study (CHEM Study), developed a textbook and laboratory guide which was used on an experimental basis in twenty-four high schools during the academic year 1960-1961. The content of this course, like the CBA course, differs substantially from that presented in conventional high school chemistry textbooks.

The deplorable state of high school chemistry courses was, in the words of Dr. Glenn T. Seaborg, Chairman of the CHEM Study group, the result of:

> *. . . the surprising and persistent general lack of interest in high school chemistry and lack of communication with high school teachers and administrators on the part of college professors of chemistry and professional chemists. This situation has gone on for decades, and high school chemistry courses of the recent past are an ugly monument to it.*
>
> *Happily, there are many examples of a rapid change for the better, including participation of the American Chemical Society nationally and through its local sections.*[8]

The CHEM group, like the others, represents a collaborative approach of university scientists, teachers, and educators—an approach that has fully proved its effectiveness. In this instance, the objectives included not only the production of a new text, but new laboratory experiments, manuals, films, and supplementary reading materials. From the beginning, Dr. Seaborg says:

> *We decided . . . to have the high school chemistry courses strongly based on experiment and to have the text thoroughly dependent upon and integrated with laboratory experiments, with the supplemental use of integrated films whenever they would be helpful.*

The CHEM Laboratory Manual Table of Contents is reproduced as Appendix C-1, and the CHEM film list as Appendix C-2.

3. *Biology*

The changing character of biological science is a major factor in curriculum development. Advances in understanding of living things are dependent upon advances in related sciences. Until developments in chemistry and physics evolved useful generalizations regarding matter and energy, biology could be little more than a description of living organisms; a penetrating analysis of what makes something alive was not possible.

Contemporary secondary school biology books reflect very few of the rapid and recent advances in biology. The wide gap between the science of biology as it exists in the research laboratories, and the science of biology as it is presented to secondary school students, led to a new program for the development of materials for teaching contemporary biology in secondary schools. With support from the National Science Foundation, the American Institute of Biological Sciences established the Biological Sciences Curriculum Study (BSCS). After a year and a half of preliminary work, the BSCS, in the summer of 1960, gathered together teachers, research biologists, and curriculum specialists to produce new materials for high school biology instruction. Dr. H. Bentley Glass, Chairman of the Biological Sciences Curriculum Study, described the purpose of the study in a letter to the New York Times of July 16, 1960.[9]

> *The BSCS and its parent organization, the American Institute of Biological Sciences, are concerned not only with improving the subject-matter being presented under the title "biology" but also with the manner of presentation, the emphasis and the focus. . . .*
>
> *As the BSCS works on the high school biology program, we hope that biology—and indeed all science—will be presented as an unending search for meaning, rather than as a body of dogma . . . our main objective is to lead each student to conceive of biology as a science, and of the process of science as a reliable method of gaining objective knowledge.*
>
> *To a very great extent the key to this understanding lies in meaningful laboratory and field study which incorporates honest investigation of real scientific problems. However, today, what commonly passes for "lab" is often routine cookbook-type exercises or a mere naming of structures on drawings and answering of questions by looking them up in a textbook. . . .*

The aim of the BSCS is to place biological knowledge in its fullest modern perspective. If we are successful, students of the new biology should acquire not only an intellectual and esthetic appreciation for the complexities of living things and their interrelationships in nature, but also for the ways in which new knowledge is gained and tested, old errors eliminated, and an ever closer approximation to truth attained.

Until recently, the availability of teaching materials dealing with recent advances in biology has been very limited. The typical biology teacher was faced not only with inadequate textbooks and other materials, but also with inadequate training. College biology curricula for secondary school teachers have been primarily in terms of nineteenth century biology, and most teachers, even if recently trained, had learned little or nothing of the important advances since 1940.

With the assumption that modern advances in biology are significant and important for secondary school teaching, the Biological Sciences Curriculum Study set out to prepare new material which would present a much more unified and up-to-date treatment of biology for secondary schools. Three versions of high school biology textbooks and laboratory guides were prepared. The materials for these three somewhat different courses were bound with different colored covers and identified by colors. The Green Version was written to give greater emphasis to ecology. The central concern in this version is the interaction of populations, communities, and the world biome. The Yellow Version places a somewhat greater emphasis on the cellular approach to plants, animals, and microorganisms. The Blue Version emphasizes the molecular and cellular levels. Most of the same topics appearing in the Yellow and Green Versions are treated, but the level of presentation is somewhat more advanced and there is more emphasis on the teaching of biology to illustrate the methods of scientific inquiry. The tables of contents from these three versions are reproduced in Appendix D-1, 2, and 3, and will illustrate the topics presented in each version and the great overlap in the versions.

A brief glimpse at the chapter headings in the three versions, in comparison with those in current published textbooks, immediately suggests the difference in emphasis. There are no chapters on vertebrates or fungi or similar subdivisions of subject matter. The emphasis is upon the unity among living things with an attempt to bring out the broad underlying principles which apply to all living things. As stated by Dr. Glass:

> *. . . we must make the warp and woof of our treatment of the subject-matter consist of the great biological themes such as the interdependence of structure and function, regulation and homeostasis, the genetic continuity of life, its evolution, diversity of type bound up with unity of pattern, and the relation of organism to environment. These must be treated at all levels of organization, from the molecular level to that of the ecosystem, and at all levels of process, from the chemical reaction through the growth and development of the individual to the evolutionary changes with time.*[10]

The laboratory manuals for the BSCS versions differ from those accompanying most standard textbooks today in that most of the work in the BSCS program requires students to approach laboratory work as a process of inquiry rather than as a process of verification of stated fact. The laboratory guides do not include numerous blanks to be filled in by the student as he studies material. There is a general emphasis on the collection and interpretation of data, including extensive graphic analysis.

In addition to the textbooks and laboratory guides, the BSCS program has produced several *Laboratory Blocks*, each consisting of one selected aspect of biology, which provide material for an investigation in depth. Each block is intended as a substitute for five or six weeks of ordinary class instruction including discussion and laboratory work. This plan draws a sharp distinction between the conventional *illustrative* function of laboratory work and what may be called the *investigative* function. The Foreword in the BSCS Laboratory books makes this distinction clear, in terms of the paramount aim of science teaching in general education—the aim of preparing citizens, most of whom will be non-scientists, to take an intelligent stand in the affairs of a scientific age. It says: "No matter how much you learn about the facts of science, you will never quite understand what makes science the force it is in human history, or the scientists the sorts of people they are, until you have shared with them such an experience. The laboratory and the field are the scientists' workshops. Much reading and discussion are necessary in scientific work, but it is in the laboratory and field that hypotheses are tested."

"Properly to realize this aim," says Bentley Glass,[11] "the student's experience must involve real, not make-believe, scientific investigation. One must approach the frontiers of existing knowledge and ask questions the answers to which are unknown—to the teacher and scientist as well as to the student." This is not too difficult in biological investigations, where so many variables exist. What is more difficult is to plan investigations in such a way that groups of students—ordinary classes—of a wide range of individual aptitude and ability can participate. This is what the Laboratory Block program undertakes to do, with its penetration of particular problems in some depth and its emphasis upon group and team cooperation in obtaining data, checking them by independent replication, and pooling them for quantitative analysis.

Four of the blocks in the series are entitled *Animal Growth and Development, Interdependence of Structure and Function, Plant Growth and Development,* and *Microbes: Their Growth, Nutrition, and Interaction.*

Another contribution designed to improve the character of independent student laboratory and field study for gifted or superior students is the collection of 100 sample research problems suggested by research workers in biology. Included with the outline of each research problem are selected references to aid the student in a serious analysis.

II. SUGGESTIONS

The preceding sections describe the unique function of the laboratory in developing in students a valid concept of scientific activity.

In this section a number of suggestions are made which may help in developing a successful program of laboratory instruction. The suggestions are general in character and should be applicable in communities of various educational, economic, and cultural conditions.

The suggestions are not necessarily arranged in order of importance nor in order of developmental sequence.

A. THE TEACHER

The most important element in any program of laboratory science instruction is a well-prepared teacher. A good teacher can innovate, adapt, and create materials for at least minimal opportunities for student participation in the laboratory, even in the face of stringent fund limitations. A poor teacher will not know how to use effectively a well-equipped laboratory and may, by improper instructional procedure, lead students to develop misconceptions about science and the nature of scientific investigation.

1. *Education*

a. Undergraduate programs for science teacher preparation must contain substantial courses in science which include current developments and concepts. In the recent "Guidelines for Preparation Programs of Teachers of Secondary School Science and Mathematics," reporting a joint study of the National Association of State Directors of Teacher Education and Certification and the American Association for the Advancement of Science, the following common guidelines are given:

> *(1) The program should include a thorough, college-level study of the aspects of the subject that are included in the high school curriculum.*
>
> *(2) The program should take into account the sequential nature of the subject to be taught, and in particular should*

provide the prospective teacher with an understanding of the aspects of the subject which his students will meet in subsequent courses.

(3) The program should include a major in the subject to be taught, with courses chosen for their relevance to the high school curriculum.

(4) The major should include sufficient preparation for the later pursuit of graduate work in one of the sciences or in mathematics.

(5) A fifth-year program should emphasize courses in the subject to be taught.

(6) The program should include work in areas related to the subject to be taught.

(7) The program should include preparation in the methods especially appropriate to the subject to be taught.

(8) The program should take into account the recommendations for curriculum improvement currently being made by various national groups.

As an example of the application of these general guidelines to a particular field, the following amplification for the training of prospective biology teachers may serve:

(1) Essential concepts to be included are (a) the characteristics of living organisms in terms of maintenance, regulation, behavior, reproduction, genetics, development, evolution, and systematics; (b) the interrelationships of living organisms with their physical and biotic environments; (c) significant emphasis on plant, animal, and microbiological sciences alike; (d) strong emphasis on actual living materials in laboratory and field; (e) emphasis on science as investigation and inquiry, especially through experimental methods.

(2) A broad course in general biology, or the equivalent derived from separate courses in botany, zoology, and microbiology; plus advanced courses.

(3) A total of biological courses amounting to approximately a full year of college work, with advanced courses selected so as to avoid undue specialization and to achieve a balanced program of biology.

(4) Courses relevant neither to the high school program nor to preparation for graduate study should be discouraged.

(5) Not less than half the courses beyond the baccalaureate and leading to a master's degree should be in biology.
(6) Work in the related sciences (physics, chemistry, geology, mathematics, psychology) should approximate one full year of the college program.
(7) Training in laboratory and field work is especially important. Design of experiments and development of demonstration equipment should be taught. The aim is training that will provide the prospective teacher with the special skills and techniques necessary to conduct an effective laboratory program in the high school courses to be taught. The conventional laboratory and field work in many present college courses does not do this.
(8) Attention should be given specifically to the programs of the Biological Sciences Curriculum Study. Flexibility and choice of various alternative ways of teaching should be maintained in place of absolute uniformity and inflexibility in teacher preparation.

b. Opportunity should be provided for laboratory experiences similar to those herein recommended. University and college courses of instruction and laboratory work must be reviewed so that prospective teachers receive, by example, knowledge and understanding of the correct function of the laboratory.

c. The prospective teacher should be encouraged to work in a laboratory with alternative sets of equipment to gather experience with a variety of means for demonstrating or investigating a single scientific concept phenomenon.

d. The formal science education of teachers should demonstrate clearly the close and essential relationship of individual laboratory work by students to the objectives of the course. Teachers in training must actually participate in laboratory experiments, just as they will require their future students to do.

e. The concept of continual evolution and development of experimental materials and the need for variety in laboratory work should be injected into the education program for teachers. This can be done, in part, by a program of continued experimentation on the character and content of laboratory work in the teacher education institution and in part by ensuring that samples of equipment, draft copies of experiments, and reports prepared elsewhere are made available to the student teacher.

f. Strengthening the preparation of teachers is not enough. Ways must be found, such as summer institutes, in-service programs, and other devices, to bring and keep all teachers up to date in their knowledge of science and of new materials and devices useful in the teaching of science.

B. THE CONTENT AND STRUCTURE OF LABORATORY WORK

1. *Substantive*

a. The laboratory should be used to enable individual students to develop concepts out of observations, measurements, and generalizations.

b. Concepts developed should reflect insofar as possible recent developments.

c. Wherever possible, materials used should be those with which the student is familiar in his own environment. This is particularly important in studying biological topics.

d. The laboratory experiments should be integrated with other portions of the science course—discussions, text, recitations, and demonstrations. They should both support the material assigned in other portions of the course and rely upon information and knowledge acquired there by the student. It is sometimes useful and convenient to let the laboratory work on particular experiments precede its classroom study.

e. Although some experiments should be performed by each student alone, some require more than one person for control and observation. Some scientists claim that maximum benefit is derived if two or three students work together on such experiments. If limitation in funds, equipment, or facilities makes individual or small group experimentation impossible for most of the course, at least a few experiments for small groups should be provided.

f. Sole [illegible]e on routine or prescription type experiments should be avoided. Open-ended assignments leaving as much as feasible for the student to discover by progressive observations and analysis are highly desirable.

g. Experiments should be designed to draw on student knowledge acquired from other courses and to demonstrate that scientific activity is based on optimum utilization of accumulated knowledge.

h. A variety of techniques can be used to give students the experience uniquely sought from the laboratory. No one alone is satisfactory, but a judicious combination can be effective, determined in part by economic conditions, availability of equipment, competence of the teacher, and the nature of the scientific principle or concept to be developed. For nearly any school in any setting a reasonably satisfactory combination of individual experiments, group experiments, teacher demonstrations, and films can be organized.

2. *Procedural*

a. Science courses, including the laboratory portion, should be continually reviewed to keep them up to date in content and procedure.

b. Classroom science teachers, currently active scientists, and science educators in teacher education institutions should collaborate in the review and should help to determine at any time whether major revision, adaptation of materials developed elsewhere, or minor changes for modernizing the course are needed.

c. The reviewers should reach agreement on principles to be developed in the laboratory, on objectives of the course which might best be directed to details of the experiments, and on equipment, materials, and facilities needed.

d. Students can develop an understanding of a given concept, or a particular principle, using various levels of sophistication in equipment and experiment design. Conversely, a single and simple piece of apparatus might be used to develop concepts of different levels of sophistication. The syllabus might well contain two or more alternative sets of experiments or sets of recommended apparatus for developing the essential elements, thus providing for a minimal but still somewhat satisfactory laboratory program, even in the face of material and financial limitations.

e. Teachers should be encouraged to innovate and experiment with new laboratory procedures including open-ended projects by individual students. This requires high-caliber teachers.

f. Centers should be provided at one or more universities associated with teacher education institutions for continual examination of new materials and techniques, for making information available to teachers in the schools, and for injecting new life and meaning into what might otherwise become a stereotyped program.

C. APPARATUS AND MATERIALS

1. Apparatus should be selected for its functional use as an essential part of assigned laboratory experiments or for its usefulness in student projects.

2. Avoid purchase of complex pieces of equipment if simpler and more easily maintained items are available which will serve the purpose satisfactorily in the experiment or the course. Unduly complicated apparatus may obscure the process under investigation.

3. A few relatively advanced research-type pieces of apparatus can be used to advantage by a well-prepared teacher to help good students work on more challenging problems. Purchase should be made only if such usage will result and if funds for the general purpose of the laboratory are not jeopardized.

4. Avoid purchase of equipment which cannot be repaired or for which replacement parts are unobtainable.

5. While recognizing that care in handling and maintaining apparatus will prolong its life, this concern should not be carried to such an extreme that students are prevented from handling and using the equipment.

D. BUILDINGS AND SERVICES

1. *Rooms and Facilities*

a. The structure should meet basic requirements for shelter, security against damage or theft, and flexibility for various uses; and should be designed if possible with room for expansion.

b. The design and character should be compatible with other public buildings in the community.

c. There is probably no single arrangement for the laboratory and its relation to other course activities that is best. In any arrangement, it is important to preserve the functional and substantive relationship between experiments, classroom discussions, and examinations.

d. For biology in particular there should be an outdoor area for plant growth and ecological studies. When this cannot be provided near the school, classes should make planned field excursions to utilize the rich natural resources of the country. A natural preserve, in addition to providing a source of occasional specimens and practice in identification, should be a place for the study of natural changes and interactions among living things and their physical environment, and to this end should be little disturbed. The area should include as much native plant and animal life as possible but need not be large. A small marsh, wooded slope, or idle corner of the schoolyard can serve this important function.

2. *Minor Notes on Services and Special Equipment*

a. Appropriate storage with locks is needed for a variety of materials. If possible, include separate storage cabinets for materials in use by individual students in experiments or projects. Some apparatus, of course, requires special care to keep it free from dust or other contaminants.

b. The laboratory must include bench or table space. Some planners recommend approximately four lineal feet of space per student. This can be as simple as movable tables located in the central portion of the room, to which could be added a series of cabinet-type benches along a portion of the walls, containing sinks, water, and perhaps gas, with wall cabinets above. It is helpful but not essential that these be designed for laboratory usage. Relatively inexpensive units can be satisfactory.

c. Outlets for alternating current at regional standard voltage and frequency should be conveniently located throughout the room. Flexibility of table location in the center of the room can be obtained if overhead drop-cord outlets are provided.

d. Direct current lines are not essential. Economy and convenience can be achieved by use of rectifier units of appropriate size and characteristics to convert available AC to DC.

e. Water faucets, sinks, and drains can be economically arranged along one or more walls of a laboratory room. A bench equipped with such facilities, standing away from a wall, could serve for instructor demonstrations.

f. Hot water piped to sinks is desirable but not essential.

g. If available in the community, natural gas should be piped to all fixed benches for use with torches and burners. Otherwise, sources of heat energy most economically obtainable should be used.

h. Adequate lighting should be provided for every room, preferably with an ambient level of approximately 75 to 125 foot candles. Special lighting for demonstrations may be desired with provision for darkening the room for projection purposes.

III. THE LABORATORY OVERSEAS

The material in the previous sections is believed to be relevant to the teaching of science in any country, although materials, facilities, or practices found useful in one country might fail in another because of a variety of cultural, economic, and educational differences.

This section presents notes on points which may be important under different cultural and technological conditions. It should not be considered by itself, but only in the context of what has been said earlier.

These notes are grouped under headings corresponding to parts of Sections I and II, which are identified by page numbers for the reader's convenience.

A. THE STUDENT

(Page 8)

1. Recognition of differences in technological richness of cultures is important for curriculum planning, but it is too often neglected. It is harmful to educational effectiveness either to ignore the advantages available to students living in a technologically advanced region or to assume a familiarity with materials and devices that in fact does not exist in the community.

2. It is hazardous to introduce scientific concepts and the products of science by using as examples materials with which the student may be unfamiliar. The degree of technological advancement in an area should determine the materials used to promote science as a process of inquiry and to show the concepts, materials, and technological products that result from such inquiry.

B. THE PREPARATION OF TEACHERS

(Pages 9 and 28)

The pattern of renewed collaboration between professional educators and scientists in the United States is important for those planning new programs for teachers in developing countries.

1. In some countries, preparing teachers of science to use the laboratory effectively as an integral part of the course conflicts with the understandable cultural aversion to work with the hands. Such feelings

are not unknown even in the Western World. A determined effort is needed to demonstrate that laboratory work is not mere manual labor which can be assigned in accordance with tradition to others of lower class. The development of a feeling for the interaction of materials and objects is an essential element of learning through laboratory work. The investigator must have direct control over the equipment, instruments, or ingredients in an experiment. It is important that he sense the relation of what he does with his hands to the consequences observed, and to the results he measures. For example, he needs to assume personal responsibility for the cleanliness of the vessels or instruments to be used in order to help avoid introduction of contaminants.

2. Reference has already been made to the need to reflect differences in cultural and economic conditions in the curriculum. In a rapidly changing country, the teacher should be alert to changes brought about by new developments in the community, and be ready to revise science courses to take advantage of such developments. Participation by the teacher in some of these community changes may help guarantee effective correlation.

3. Summer institute programs for teachers are an excellent means of introducing new material or curricular changes. Where this is not practical, an alternative method is the use of in-service lessons or demonstrations on film. Where television has been used to broadcast science lessons for students in classrooms in the United States, the greatest gain is often made by the teacher. If such presentations reflect superior teaching techniques, or very effective use of materials which would also be available to the classroom teacher, a considerable improvement in the local teacher can result.

4. While such filmed courses cannot replace ordinary classroom instruction, especially laboratory instruction, they act as catalysts for the modernization of science teaching and the improvement of necessary laboratory instruction. Instruction in science involves a certain amount of demonstration and straight presentation of facts. Some of this material can be presented satisfactorily by films, whether projected in the classroom or broadcast over television. Where facilities permit, schools should consider providing such resources as an aid to the teacher, thus allowing him more time for laboratory preparation and for independent work with students.

Many of the above activities carried on in the United States would not be readily applicable in all other countries. They are mentioned to emphasize the importance of providing some feasible and appropriate mechanism for continued professional and scientific growth of the teacher and for interaction with scientists or others engaged in experimental programs of instruction.

C. THE PHYSICAL PLANT AND FACILITIES

(Page 12)

No unique set of specifications for facilities and equipment can be defended as absolutely required for an effective science course, including laboratory. The significant question is: What facilities and equipment would be of optimal educational value for a group of students in a particular cultural setting with a given level of community or national resources?

The fact that increasing amounts of economic resources must be invested in education by all countries around the world dictates that care be exercised in deployment of these resources. Buildings and facilities should be reasonably compatible with other public buildings in the community. Funds for construction should be balanced realistically with those needed for laboratory equipment and supplies, or for better preparation of teachers so that they might use the available laboratory facilities more effectively.

Whether facilities are elaborate, as in a technologically advanced culture, or minimal in a newly-developing area, laboratory instruction can be given, and should be included in a secondary school science course.

An area for outdoor study of native plants and animals, even a small one with commonplace examples, can be of great value in the teaching of biology. Such study is inexpensive and can be carried out with little disturbance to wild life. Natural preserves are particularly important for schools in rural areas where native plants and animals persist and where laboratory equipment is scarce. Living examples can be brought into the classroom for observation and experiment.

It would be both presumptuous and mistaken to suggest that some proposals for new types of secondary school science and laboratory facilities in the United States be adopted in developing countries. Nevertheless, some of the proposals now being given serious consideration in the United States for improvement of facilities and educational practices may have elements of importance for planning new facilities elsewhere. The techniques for development of new materials and the underlying relationships of laboratory work to the course as a whole have significant implications for adaptation or development of programs in other countries. Without attempting to reconcile different proposals or to evaluate suggestions, the items appearing on pages 14 - 16 are noteworthy. The comments do not necessarily relate directly to the laboratory, but would influence school organization in general and open the way for more adequate use of time and space for laboratory work.

D. NATIONAL OR REGIONAL PROGRAMS

Initiation of steps toward some of the objectives suggested above sometimes can be done best through pilot or demonstration projects. Special studies or experimental production facilities may also be essential. In addition, it is important to increase public awareness of the need for greater utilization of science in furthering development of a community and of the opportunities for employment of those who develop laboratory and other scientific skills. Some suggestions for regional programs are:

1. *Centers for Curriculum Development and Experimentation*

Depending upon the size of the country and the extent of need, one or more centers at teacher education institutions could re-examine the science curriculum. Specific and parti lar attention should be directed to the laboratory portion. Teachers ntists should be drawn to the center from various parts of the coun work in the program.

Also depending upon local conditions, either one curriculum or a small set of alternatives could be established for the region, taking into account variation in capabilities and facilities.

These centers may have a useful function in adapting curricular materials, developed elsewhere, to the needs of the region. The Biological Sciences Curriculum Study in the United States is most insistent that its materials not be used unmodified in an area where the flora and fauna are different from those in the United States. BSCS stands willing to help in the adaptation of its materials to other biological environments. These national or regional Centers for Curriculum Development would be suitable instruments in such cooperation.

To facilitate introduction or extended use of new curricula and experiments, seminars, workshops, or regional meetings with teachers should be set up. A subsidy should perhaps be provided for local teachers and schools to participate in such planning activities and to acquire new materials for the laboratory.

Local circumstances will dictate whether or not these centers are appropriate locations for retraining and upgrading institutes for teachers. The centers at least should take the responsibility to see that such institutes are provided.

2. *Examinations*

Examinations serve an important function in maintaining uniformity of standards, and in many cases they are also used as a basis for selection where school facilities are insufficient to accept all applicants. It is important to recognize, however, that examinations used as a basis for selection tend to determine in advance the content and emphasis of any prescribed course of study no less than does the formal syllabus. Unless the examination system specifically allows for flexibility, it may in fact become a powerful force against change and thus seriously hamper efforts to improve teaching. New methods intended to introduce more modern concepts into a course are particularly likely to be hindered by the "external" examination in which the examiners have not participated in the actual preparation and teaching of a course in its improved form. This single factor may do more to prevent creative experiments with improved teaching than any lack of funds or imagination.

It is, therefore, extremely important for national or state education administrations to make sure that examinations do not become an end in themselves, but remain a means for evaluating, maintai ng minimum standards, and perhaps acting as an incentive toward im ovement. To do this, the examinations themselves can make room for change by offering a choice among several alternative questions; by allowing the possibility that a given question may be satisfactorily answered in more than one way by students with different sorts of preparation; and, most important of all, by emphasizing questions which require a knowledge of fundamental concepts and methods rather than detailed facts and numbers.

Finally, it may be pointed out that flexibility can be achieved and unwarranted preoccupation with examinations can be reduced by means of a system of partial accreditation whereby some superior students are permitted to advance without examinations. If, for example, approximately 15 per cent of students from a selected list of schools were accepted on the basis of the school's recommendations without the external examination, a considerable degree of flexibility to try improved methods in the best schools will result, and at the same time an incentive toward superior work on the part of both school and student will have been established. The chief purpose of the examinations—that of maintaining uniform minimum standards—will not have been changed.

Care should be taken to see that examinations include questions based upon the laboratory work (otherwise the laboratory work will inevitably lose emphasis), and at the same time that they reflect a proper recognition of the role of the laboratory and allow for variations in the type and number of experiments that students may have been able to perform.

3. *Production of Laboratory Apparatus*

Where private industry cannot be expected to venture into production of new laboratory apparatus without some assurance of sales, a government subsidy of one or more manufacturers would probably be necessary. This may even call for establishing a new company which ultimately could operate at a profit without subsidy.

Alternatively, shops at curriculum development centers could develop models of apparatus to be constructed, and contracts could then be let by the government to manufacturers on competitive bids for specified quantities, the quantity of sales being guaranteed by the government if local school purchases were insufficient.

Whichever approach is taken, the production organization should not be so elaborate as to discourage periodic review of the laboratory experiments. The production organization should respond quickly to recommended changes.

The intent would be to establish in each country or region facilities for mass producing items of laboratory equipment, at low cost and with replaceable parts. Several advantages should follow: Local labor would be taught manufacturing skills; apparatus should be more readily available for purchase, repair, and replacement; the quantities needed would be large enough for a given item to justify establishment of mass production techniques of value to the country if they did not exist previously; a production and distribution system would be thus created to facilitate introduction of new materials as they are developed without reliance on imports.

In most developing countries supplies of equipment and materials for laboratory use will generally be limited for some time. It is, therefore, particularly important that the teacher be prepared to use simple equipment, draw on resources of the community or countryside, and use field trips for observation and analysis as alternative means of providing laboratory opportunities for students.

The capability of the teacher to improvise rests squarely on sound preparation including an understanding of the function of the laboratory in a science program. It depends also, of course, upon the freedom given him by the examination system.

4. *Centers for Science Film Production*

The school ministries or other government agencies in a country or region might cooperate in establishing and supporting a center for producing a variety of science films—both new films and adaptations of those obtained elsewhere in the world to satisfy special needs in the region. Some could be directed toward teacher education; some could supplement the laboratory work by showing experiments otherwise unavailable; some could provide demonstrations using equipment most schools could not obtain; and some could show the availability of science careers in the region.

An important advantage of a national or regional film production program is that local scientists and teachers can be shown on the film, working in local laboratories. This stimulates scientific interest in the culture of the region.

5. *Programs for Interpreting Science to the Public*

The importance of science education including its laboratory work should be made known to the public at large in order to generate support for government action and to develop parental and community understanding and support of the work of students. Appropriate use of news media, of exhibits, of lectures, of various organized groups to distribute information, and of films for the public will all help increase public understanding.

A good science museum provides a very valuable resource both for school classes and the general public in a fairly wide area. Besides offering permanent and special exhibits, film showings, a planetarium, nature area, etc., it can very well serve as a focus and headquarters for science clubs and for a national program of science fairs. Here the results of recent scientific research by local scientists or the implications of major scientific discoveries can be illustrated and explained through exhibits, lectures, or films, and thus the scientific development of a country can be put into perspective.

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In summary, the laboratory is an essential element of an effective program of science instruction. Improvement in laboratory instruction, as well as the rest of the science curriculum, can be made wherever there is determination that it be done, where imaginative and competent scientists want to do it and are given adequate support and freedom, and where the development involves teachers and is fed into the teacher education institutions through collaborative efforts.

Materials selected for new programs in various stages of development and use in secondary schools in the United States are reflective of experiences of students living in the United States, and would not necessarily be appropriate for use elsewhere. We do not intend to imply that any of the materials are usable without modification in a program developed for some other country or region. They may, however, be helpful guidelines to the developers of programs elsewhere.

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2. *Ibid.*, p. 72.
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5. Killian, James R., *Physics*, Physical Science Study Committee, Boston: D. C. Heath and Company, excerpt from Preface, p. vi.
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7. Strong, Laurence E., and M. Kent Wilson, "Chemical Bonds: A Central Theme for High School Chemistry," *Journal of Chemical Education*, 35:56, February 1958.
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9. Copyright by The New York Times. Reprinted by permission.
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APPENDIX A. PHYSICAL SCIENCES STUDY COMMITTEE

1. Laboratory Guide for Physics

CONTENTS

2. PSSC Physics Films
(December, 1962)

Produced by Educational Services, Inc., and distributed by Modern Learning Aids, 3 East 54th Street, New York 22, N. Y., to whom inquiries regarding prices should be directed.

TIME AND CLOCKS

John King, MIT

Discusses concepts of time measurement and shows various devices used to measure and record time intervals from 1 second down to 10^{-8} seconds. Points out that the accuracy of a clock can be judged only by comparison with another clock. The question of what time is, psychologically, is raised briefly as well as the question of a possible limit to the subdivision of time.

#0101 27 minutes

LONG TIME INTERVALS

Harrison Brown, CAL. TECH.

A discussion of the significance of long time intervals with a detailed description of radioactive dating arriving at an estimate for the age of the earth.

#0102 24 minutes

SHORT TIME INTERVALS

Campbell L. Searle, MIT

A study of the extension of the senses to deal with very short time intervals. As an example, special techniques reveal complexities in a flash of lightning which are not ordinarily perceptible to the eye. Timing devices shown include moving cameras, pen recorders and the oscilloscope, with an explanation of its use in these measurements.

#0119 22 minutes

MEASURING LARGE DISTANCES

Fletcher Watson, HARVARD

Using models of earth, moon and stars, Dr. Watson describes the place of triangulation, parallax and the inverse square law for light in geophysics and astronomy; his demonstrations point up the immensity of interstellar space, and suggest the complexities of measurement on this scale.

#0103 29 minutes

MEASURING SHORT DISTANCES

Dorothy Montgomery, HOLLINS COLLEGE

Starts with the centimeter scale, moves on to microscopic dimensions, and then to the dimensions of atoms by means of Erwin Mueller's field emission microscope. Shows how calibration of instruments can give us accurate knowledge of these small distances.

#0104 20 minutes

CHANGE OF SCALE

Robert Williams, MIT

Demonstrates that change of size necessitates change in structure of objects; uses specially constructed props to emphasize scaling problems, then shows practical application of scale models as used in the construction of harbors, study of ship design and movie-making.

#0106 23 minutes

STRAIGHT LINE KINEMATICS

E. M. Hafner, ROCHESTER

Notions of distance, speed and acceleration discussed; graphs of all three versus time are generated using special equipment in a real test car; relationships among them shown by measurements (and estimates) of slopes and areas from the graphs.

#0107 33 minutes

VECTORS

Albert V. Baez, PSSC

Vectors are demonstrated in a high school classroom. Rubber models are used to show vector displacement in two and three dimensions. Vector addition, scalar multiplication of a vector and other concepts are introduced.

#0108 28 minutes

VECTOR KINEMATICS

Francis L. Friedman, MIT

Velocity and acceleration vectors are introduced and shown simultaneously for various 2-dimensional motions including circular and simple harmonic. The vectors are computed and displayed as arrows on a cathode ray tube screen by a digital computer, and their relationships are discussed.

#0109 16 minutes

PSSC PHYSICS FILMS

ELEMENTS, COMPOUNDS AND MIXTURES (Color)

Ival Johns, MONSANTO CHEMICAL COMPANY

A discussion of the difference between elements, compounds and mixtures, showing how a mixture can be separated by physical means. Demonstrates how a compound can be made and then be taken apart by chemical methods with identification of components by means of their physical properties such as melting point, boiling point, solubility, color, etc.

#0111 34 minutes (color)

DEFINITE AND MULTIPLE PROPORTIONS

Robert St. George, CAMBRIDGE SCHOOL
Jerrold R. Zacharias, MIT

Here is the evidence on which Dalton based his conviction that matter came in natural units, atoms; the chemical laws of definite proportions demonstrated by electrolysis and recombination of water; and multiple proportions by the quantitive decomposition of N_2O, NO and NO_2.

#0110 30 minutes

CRYSTALS

Alan Holden, BELL LABORATORIES

Demonstrates the nature of crystals, how they are formed and why they are shaped as they are. Shows actual growth of crystals under a microscope; discusses how they may be grown. Relates these phenomena to the concept of atoms.

#0113 24 minutes (black and white or color)

BEHAVIOR OF GASES

Lee Grodzins, MIT

The Brownian motion of smoke particles is shown by photo-micrography and compared with a mechanical analogue. This evidence for molecules in chaotic motion is contrasted with the orderly behavior of gases as shown by Boyle's Law experiment. Animation and mechanical analogues are then used to develop a model for gas pressure based on chaotic molecular motion.

#0115 15 minutes

RANDOM EVENTS

Patterson Hume and Donald Ivey, UNIVERSITY OF TORONTO

This film shows how the over-all effect of a very large number of random (unpredictable) events can be very predictable. Several unusual games are played to bring out the statistical nature of this predictability. The predictable nature of radioactive decay is explained in terms of what is shown.

#0116 31 minutes

MEASUREMENT

William Siebert, MIT

The measurement of the speed of a rifle bullet is used as the basis for a discussion of the art of measurement. Problems that are met and discussed include noise, bias, use of black boxes and the element of decision in all measurements.

#0105 22 minutes

INTRODUCTION TO OPTICS (Color)

E. P. Little, PSSC

Deals with approximation that light travels in a straight line; shows the four ways in which light can be bent—diffraction, scattering, refraction and reflection; refraction illustrated by underwater photography to show how objects above water appear to a submerged skin diver.

#0201 23 minutes (color)

PRESSURE OF LIGHT

Jerrold R. Zacharias, MIT

Light pressure on a thin foil suspended in a high vacuum sets the foil into oscillation. The film leads up to this by a discussion of the Crookes radiometer and the effect—not light pressure—that causes it to rotate. The role of light pressure in the universe is also briefly discussed.

#0202 21 minutes

SPEED OF LIGHT

William Siebert, MIT

Outdoors at night Dr. Siebert measures the speed of light in air using a spark-gap, parabolic mirrors, a photocell and an oscilloscope. In the laboratory he compares the speed of light in air and in water using a high speed rotating mirror.

#0203 23 minutes

SIMPLE WAVES

John Shive, BELL LABORATORIES

Pulse propagation on ropes and slinkies shows elementary characteristics of waves such as different speeds in different media. Effects are shown at regular speeds and in slow motion. A torsion bar wave-machine is then used to repeat these experiments to demonstrate reflection and other phenomena.

#0204 27 minutes

SOUND WAVES IN AIR

Richard H. Bolt, MIT

The wave characteristics of sound transmission are investigated with large scale equipment using frequencies up to 5000 cycles. Experiments in reflection, diffraction, interference and refraction are supplemented with ripple-tank analogies. Interference is shown in both the pattern of standing waves and in a pattern reflected from a grating. A gas filled lens is used to refract sound.

#0207 35 minutes

FORCES

Jerrold R. Zacharias, MIT

Introductory to mechanics in general, this film foreshadows later work with kinds of forces. A qualitative Cavendish experiment shows gravitational forces between small objects. Also by means of this experiment gravitational force is compared with electrical force in a simple demonstration.

#0301 23 minutes

INERTIA

E. M. Purcell, HARVARD

Demonstrates Galileo's principle of inertia using low friction dry ice pucks and multiple flash photography; develops the relation that acceleration is proportional to force, when mass is constant.

#0302 27 minutes

INERTIAL MASS

E. M. Purcell, HARVARD

A continuation of INERTIA, this film develops the relation that accleration is inversely proportional to mass, with a constant force. It shows that different objects may have the same inertial mass, by demonstrating that they have the same acceleration if the same force is applied. Finally, it distinguishes and compares inertial and gravitational masses pointing out the proportionality between them.

#0303 20 minutes

FREE FALL AND PROJECTILE MOTION

Nathaniel Frank, MIT

The behavior of freely falling bodies is explored from a dynamical point of view, leading to the proportionality of gravitational and inertial mass, the independence of perpendicular components of a motion, and the conclusion that Newton's Law is a vector relationship. Includes a slow-motion study of two balls simultaneously dropped and projected horizontally from the same height, and experiments with a large "monkey gun."

#0304 27 minutes

DEFLECTING FORCES

Nathaniel Frank, MIT

Discusses nature of forces which produce curved paths, brings out concept of centripetal vector acceleration, shows how knowledge of path and mass of an object give information on the force involved.

#0305 29 minutes

PERIODIC MOTION

Patterson Hume and Donald Ivey,
UNIVERSITY OF TORONTO

From a number of periodic motions simple harmonic motion is selected for detailed examination; a pen moving in SHM plots its own displacement—time graph; graphs of velocity and acceleration versus time are derived from it. The formula for the period of SHM is derived from the component of circular motion; the dynamics and period of SHM checked experimentally by oscillation of dry ice puck mounted between springs.

#0306 33 minutes

FRAMES OF REFERENCE

Patterson Hume and Donald Ivey,
UNIVERSITY OF TORONTO

By means of a variety of experiments on frames of references moving at constant speed or at constant accelerations, this film demonstrates the distinction between an inertial and non-inertial frame of reference, and the appearance of fictitious forces in a non-inertial frame.

#0307 26 minutes

ELLIPTIC ORBITS

Albert V. Baez, PSSC

S. rting with an elliptic orbit (as of a satellite) and using Kepler's law of areas, this film shows that the gravitational force on the satellite obeys an inverse square relation. The derivation is almost entirely geometric in nature.

#0310 18 minutes

UNIVERSAL GRAVITATION

Patterson Hume and Donald Ivey,
UNIVERSITY OF TORONTO

: law of universal gravitation is derived by imagining a solar system of one star and one plane Professors Hume and Ivey as inhabitants of planet X describe the process by

which they derived the law in their solar system. The kinematics and dynamics of planetary motion are demonstrated using various models to discuss a solar system. Satellite orbits are displayed using a digital computer.
#0309 30 minutes

ELASTIC COLLISIONS AND STORED ENERGY

James Strickland, PSSC

Various collisions between two dry ice pucks are demonstrated. Cylindrical magnets are mounted on the pucks producing a repelling force. Careful measurements of the kinetic energy of the pucks during an interaction lead to the concept of stored or potential energy.
#0318 28 minutes

ENERGY AND WORK

Dorothy Montgomery, HOLLINS COLLEGE

Shows that work, measured as the area under the force-distance curve, does measure the transfer of kinetic energy to a body, calculated from its mass and speed. A large-scale falling ball experiment, a non-linear spring arrangement and a "Rube Goldberg" graphically establish work as a useful measure of energy transfer in various situations.
#0311 29 minutes

MECHANICAL ENERGY AND THERMAL ENERGY

Jerrold R. Zacharias, MIT

This film shows several models to help students visualize both bulk motion and the random motion of molecules. It shows their interconnection as the energy of bulk motion. Demonstrates random motion and how such motion can average out to a smooth effect. Shows model of thermal conduction. Demonstrates a model using dry ice disc and small steel balls, in which bulk mechanical energy of the disc is converted to "thermal" energy of random motion of the balls. Develops a temperature scale by immersing canisters of two gases in baths of various temperatures, reading the resulting pressure; through this, explains the origin of the absolute temperature scale.
#0312 27 minutes

CONSERVATION OF ENERGY

Arthur LaCroix, NEW ENGLAND ELECTRIC SYSTEM
Jerrold R. Zacharias, MIT

Energy traced from coal to electrical output in a large power plant, quantitative data is taken in the plant; conservation law demonstrated for random and orderly motion.
#0313 27 minutes

COLLISIONS OF HARD SPHERES

James Strickland, PSSC

This is a laboratory instruction film dealing with conservation of momentum primarily intended for teachers. The film is a demonstration of the adjustments and operation of the Collision in 2-D apparatus used in the PSSC Lab III-10. The conservation of momentum is demonstrated for both equal and unequal mass spheres.
#0319 19 minutes

COULOMB'S LAW

Eric Rogers, PRINCETON

Demonstrates the inverse square variation of electric force with distance, and also the fact that electric force is directly proportional to charge. Introduces the demonstration with a thorough discussion of the inverse square idea. Also tests inverse square law by looking for electrical effects inside a charged hollow sphere.
#0403 28 minutes

ELECTRIC FIELDS

Francis Bitter, MIT

An electric field discussed as a mathematical aid and as a physical entity; experiments demonstrate (1) vector addition of fields, (2) shielding effect by closed metallic surfaces, (3) the electric force which drives an electric current in a conductor for both straight and curved conductors. Physical reality of fields discussed briefly in terms of radiation.
#0406 24 minutes

ELECTRIC LINES OF FORCE

Alexander Joseph, BRONX COMMUNITY COLLEGE

Shows how to produce electric field patterns using neon sign transformer as high voltage source. Indicates safety precautions. Fine grass seed in the interface between freon film cleaner (or carbon tetrachloride) and mineral oil align themselves to form various electric field patterns.
#0407 7 minutes

MILLIKAN EXPERIMENT

Francis L. Friedman, MIT
Alfred Redfield, IBM

Simplified Millikan experiment described in the text is photographed through the micro-

scope. Standard spheres are substituted for oil drops; an analysis of the charge related to the velocity of the sphere across field of view of microscope emphasizes the evidence that charge comes in natural units that are all alike; numerous changes of charge are shown, produced by X-rays, with the measurements clearly seen by the audience. Professor Friedman gives an introduction and running commentary; Dr. Redfield does the experiment.
#0404 30 minutes

COULOMB'S FORCE CONSTANT

Eric Rogers, PRINCETON

Shows a large-scale version of the MILLIKAN EXPERIMENT. The small charged plates of the original experiment are made very large and the effects are shown of increasing plate area and separation, and adding more batteries to charge the plates. The same electric field strength used in the MILLIKAN EXPERIMENT enables the experimenter to count the number of elementary charges on an object and measure the constant in Coulomb's law of electric force.
#0405 34 minutes

COUNTING ELECTRICAL CHARGES IN MOTION

James Strickland, ESC

This film shows how an electrolysis experiment enables us to count the number of elementary charges passing through an electric circuit in a given time and thus calibrate an ammeter. Demonstrates the random nature of motion of elementary charges, with a current of only a few charges per second.
#0408 20 minutes

A MAGNET LABORATORY

Francis Bitter, MIT

Professor Bitter's large magnet laboratory at MIT shows equipment used in producing strong magnetic fields; demonstrates magnetic effects of currents and the magnetism of iron.
#0411 20 minutes

ELECTRONS IN A UNIFORM MAGNETIC FIELD

Dorothy Montgomery, HOLLINS COLLEGE

A spherical cathode-ray tube with a low gas atmosphere (Leybold) is used to measure the curvature of the path of electrons in a magnetic field and with reference to the MILLIKAN EXPERIMENT the mass of the electron is determined. Arithmetic involved is worked out with the experiment.
#0412 10 minutes

MASS OF THE ELECTRON

Eric Rogers, PRINCETON

Using a cathode ray tube encircled by a current carrying loop of wire, measurements are taken which enable the demonstrator to calculate the mass of the electron with reference to the MILLIKAN EXPERIMENT. The calculations are brought out in detail, step by step.
#0413 18 minutes

ELECTROMAGNETIC WAVES

George Wolga, MIT

Shows why we believe in the unity of the electromagnetic radiation spectrum. Experiment shows that the radiation arises from accelerated charges and consists of transverse waves that can be polarized. Interference (Young's double slit experiment) is shown in four different regions of electromagnetic spectrum; X-ray, visible light, microwave and radiowave.
#0415 30 minutes

THE RUTHERFORD ATOM

Robert L. Hulsizer, UNIVERSITY OF ILLINOIS

Dr. Hulsizer uses a cloud chamber and gold foil in a simple alpha-particle scattering experiment to illustrate the historic Rutherford experiment which led to the nuclear model of the atom. Behavior of alpha particles clarified by use of large scale models illustrating the nuclear atom and Coulomb scattering.
#0416 40 minutes

PHOTONS

John King, MIT

Photomultiplier and oscilloscope used to demonstrate that light shows particle behavior; photomultiplier explained, amplification demonstrated, "noise" reduced; reasoning required to understand final outcome carefully discussed.
#0418 19 minutes

INTERFERENCE OF PHOTONS

John King, MIT

An experiment in which light exhibits both particle and wave characteristics. A very dim light source, a double slit, and a photomultiplier are used in such a way that less than one photon (on the average) is in the apparatus at any given time. Characteristic interference pattern is painted out by many individual photons hitting at places consistent with the interference pattern. Implications of this are discussed.
#0419 14 minutes

PSSC PHYSICS FILMS

PHOTO-ELECTRIC EFFECT (Color)

John Strong, THE JOHNS HOPKINS UNIVERSITY

Qualitative demonstrations of the photoelectric effect are shown using the sun and a carbon arc as sources. A quantitative experiment is performed measuring the kinetic energy of the photoelectrons emitted from a potassium surface. The data is interpreted in a careful analysis.

#0417 28 minutes

MATTER WAVES

Alan Holden and Lester Germer, BELL TELEPHONE LABS.

Dr. Germer presents a modern version of the original experiment which showed the wave behavior of the electron. The student sees electron diffraction patterns on a fluorescent screen. The patterns are understandable in terms of wave behavior; Alan Holden presents an optical analogue showing almost identical patterns. The electron diffraction experiments of G. P. Thomson are described by Holden who also presents brief evidence for the wave behavior of other particles such as neutrons and helium atoms.

#0423 28 minutes

THE FRANCK-HERTZ EXPERIMENT

Byron Young, REED COLLEGE

An epilogue by *James Franck*

A stream of electrons is accelerated through mercury vapor, and it is shown that the kinetic energy of the electrons is transferred to the mercury atoms only in discrete packets of energy. The association of the quantum of energy with a line in the spectrum of mercury is established. The experiment retraced in this film was one of the earliest indications of the existence of internal energy states within the atom.

#0421 32 minutes

The following three films comprise a full treatment of the energy transfer in electrical circuits. The latter two films should not be used separately. The preceding three films, starting with #0404 Millikan Experiment, followed by #0405 Coulomb's Force Constant and #0408 Counting Electrical Charges in Motion, are necessary to lay the foundation for the presentation of the latter three. This sequence of six films form a tightly knit development of the relevant subject matter, leading to the use of the principle of conservation of energy to analyze the behavior of electrical systems:

ELEMENTARY CHARGES AND TRANSFER OF KINETIC ENERGY

Francis L. Friedman, MIT

In a diode using the identical geometry of the MILLIKAN EXPERIMENT, the gain of kinetic energy of electrons flowing from the cathode to anode is measured experimentally and found to be that predicted by the results of the MILLIKAN EXPERIMENT. This measurement is made by comparing the thermal energy dissipated as the electrons strike the anode with the thermal energy produced in an identical anode by a mass falling a known distance. In this film the elementary charges as determined from the Millikan and from the Faraday experiment are shown to be the same.

#0409 25 minutes

E M F

Nathaniel Frank, MIT

Here it is shown that the energy transfers demonstrated in the preceding film (Elementary Charges and Transfer of Kinetic Energy) are independent of the geometry of the electrodes in the diode. It is further demonstrated that the energy per elementary charge delivered by a battery (its EMF) depends only on the chemical constitution of the battery. The concept of EMF is extended to describe any device which transforms energy by separating elementary charges. This discussion leads directly to the subject of the next film, Electrical Potential Energy and Potential Difference.

#0430 19 minutes

ELECTRICAL POTENTIAL ENERGY AND POTENTIAL DIFFERENCE (Parts I and II)

Nathaniel Frank, MIT

In Part I of this film, the mechanism by which a battery establishes an electric field in a circuit is analyzed and the electric potential energy stored in such a system is measured experimentally and explained theoretically.

In Part II, it is shown how the energy transformations in a steady current-carrying circuit can be obtained from measurements of potential difference and electric current, including the energy dissipated internally in the batteries used.

#0431-2 Parts I and II 54 minutes

APPENDIX B. CHEMICAL BOND APPROACH COMMITTEE

CBA Laboratory Manual

CONTENTS

(List Of Experiments For The Commercial Edition*)

APPENDIX C. CHEMICAL EDUCATION MATERIAL STUDY

1. Laboratory Manual

CONTENTS

2. Chem Study Films
(February, 1963)

Distributed by Modern Learning Aids, 3 East 54th Street, New York 22, N. Y., to whom inquiries regarding prices should be directed.

GASES AND HOW THEY COMBINE

Collaborator: Professor George C. Pimentel, University of California, Berkeley.

This film provides experimental evidence for Avogadro's hypothesis. First, some properties that distinguish gases are shown. Then, the volume of ammonia and hydrogen chloride that combine are measured quantitatively. The volume ratio is found to be 1.0. In a similar way, simple integer volume ratios are measured for the combination of hydrogen and oxygen, of nitric oxide and oxygen, and of hydrogen and chlorine. These simple integer ratios lead, logically, to Avogadro's Hypothesis.

#4103 22 minutes In color

CHEMICAL FAMILIES

Collaborators: Dr. J. Leland Hollenberg, CHEM Study Staff, and Professor J. Arthur Campbell, Harvey Mudd College, Claremont, California.

Starting with a display of actual samples of over 70 elements, the film demonstrates methods by which chemical similarities among the elements have provided the basis for dividing them logically into families. By experiment and observation, the metals, the nonmetals, and doubtful elements are grouped. Experimentally it is shown that some of the gases are chemically reactive and some are inert. The fact that elements with atomic numbers one less and one more than the atomic numbers of the inert gases are reactive, provides the clue for finding the halogen and alkali metal families. The film demonstrates how atomic numbers have provided the key to the ordering of the elements in the periodic table.

#4112 21 minutes In color

VIBRATION OF MOLECULES

Collaborators: Professor Linus Pauling, and Professor Richard M. Badger, California Institute of Technology, Pasadena. Produced in cooperation with the American Chemical Society.

All animation. The film shows the relationship between the structure of a molecule and its vibrational motions. Water, carbon dioxide, and methane are discussed in detail. The forms of the vibrations have been accurately calculated from spectral data. All vibrations have been slowed down by a factor of 10^{14}. The effect of molecular collision, or absorption of light, on molecular vibrations is illustrated. Determination of the number of possible vibrations and the analysis of complex vibrations in terms of simple harmonic motions are explained.

#4118 12 minutes In color

INTRODUCTION TO REACTION KINETICS

Collaborator: Professor Henry Eyring, University of Utah, Salt Lake City. Produced in cooperation with the American Chemical Society.

All animation. The film illustrates the mechanisms of some simple chemical reactions. It explains the effect of temperature, activation energy, geometry of collision, and catalysis upon the rate of reaction. The reaction between hydrogen and chlorine, and hydrogen and iodine are used to illustrate the concepts of the film. The speed of the action has been slowed down by a factor of 10^{14}. Potential energy curves clarify the relationship between the energy required for a reaction to occur and the relative position of the reaction particles before, during, and after the collision.

#4121 13 minutes In color

EQUILIBRIUM

Collaborator: Professor George C. Pimentel, University of California, Berkeley.

The film deals with three questions: What is chemical equilibrium? How does the chemist recognize it? How does he explain it? In answering the questions the film stresses the dynamic nature of equilibrium. Radioactive iodine tracers are used to demonstrate the dynamic molecular behavior of the substances at equilibrium in a closed system. An analogy in terms of fish population in two connected bowls, and animation using molecular models, present the concepts with striking simplicity.

#4124 24 minutes In color

CATALYSIS

Collaborator: Professor Richard E. Powell, University of California, Berkeley. Produced in cooperation with the Manufacturing Chemists' Association.

The film emphasizes that catalysts are typical chemical reactants, being unique only in that catalysts are regenerated during the reaction. It demonstrates and interprets three simple catalyzed reactions: the decomposition of formic acid, using sulfuric acid as catalyst; the reaction between hydrogen and oxygen, using pure platinum as catalyst; and the reaction between acidified benzidine and hydrogen peroxide using perioxidase in human blood as catalyst. Animation shows what takes place on the molecular level in a catalyzed reaction. Potential energy curves show the relationship between uncatalyzed and catalyzed reactions.

#4127 17 minutes In color

ACID-BASE INDICATORS

Collaborator: Professor J. Arthur Campbell, Harvey Mudd College, Claremont, California.

Proton-donor acceptor theory is used to interpret the experimental behavior of acid-base indicators. Experiments and animation show the effects on indicators of changing acidity. Equilibrium constants of four indicators are determined and the indicators arranged in order of decreasing acid strength. The competition among bases for protons is shown by mixing the indicators and showing that each changes color at different total acidity.

#4130 19 minutes In color

NITRIC ACID

Collaborator: Professor Harry H. Sisler, University of Florida, Gainesville. Produced in cooperation with the Manufacturing Chemists' Association.

With live action and animation the film applies fundamental principles to the descriptive chemistry of nitric acid. It demonstrates how nitric acid may act as an acid, as a base, and as an oxidizing agent. The acidity of nitric acid is shown in its reactions with water and ammonia. The mechanism of nitric acid as an oxidizing agent is discussed in terms of electric cell potentials, rates of reactions, and activation energies. Animation using molecular models, activation energy curves, and potential energy diagrams graphically clarifies the concepts of the film.

#4136 18 minutes In color

MOLECULAR SPECTROSCOPY

Collaborators: Professor Bryce Crawford, Jr., and Dr. John Overend, University of Minnesota, Minneapolis.

This film uses laboratory experiments, molecular models, and animation to show details of the infra-red light absorption process and its relation to molecular properties. The film stresses the concept of natural vibrational frequencies in molecules. Further, it demonstrates the use of the infra-red spectrum in identifying molecules and determining their molecular structure.

#4142 23 minutes In color

IONIZATION ENERGY

Collaborator: Professor Bruce H. Mahan, University of California, Berkeley.

The film presents two methods of measuring ionization energy: photo-ionization, and electron bombardment. A high vacuum system is used with a simple conductivity cell. The photo-ionization of sodium by the use of a mercury light source and monochromator is carried out. The electron bombardment method is then demonstrated with sodium and three inert gases. Animation shows what occurs on the atomic level during the ionization process. Relation of ionization energy to chemical reactivity is explained.

#4151 22 minutes In color

SYNTHESIS OF AN ORGANIC COMPOUND

Collaborator: Professor T. A. Geissman, University of California, Los Angeles.

The film shows the synthesis of 2-butanone, a ketone, from 2-butanol, an alcohol, as an example of a common type of organic synthesis. It discusses three basic steps: synthesis, purification, identification. In the synthesis, 2-butanol is oxidized by sodium dichromate and sulfuric acid to yield 2-butanone. Purification is accomplished by solvent extraction, followed by distillation of the 2-butanone. The identity of the product is established by forming a solid derivative of the 2-butanone and determining its melting point, and is confirmed by infra-red spectroscopy.

#4163 22 minutes In color

FILMS IN PREPARATION

GAS PRESSURE & MOLECULAR COLLISIONS

Collaborator: Professor J. Arthur Campbell, Harvey Mudd College, Claremont, California.

The film explores the relationship between gaseous pressure and molecular collisions. The effects of varying the number of molecules per unit of volume and of varying the temperature are studied. The experimental study of the relative rates of effusion of hydrogen, oxygen, carbon dioxide and sulfur-hexafluoride leads to the quantitative relationship between molecular weight, molecular velocity and absolute temperature. Mechanical models illustrate the experimental observations.

#4106 Black & white

CRYSTALS: PROPERTIES & STRUCTURES

Collaborator: Professor J. Arthur Campbell, Harvey Mudd College, Claremont, California.

Crystals have plane faces, sharp edges, sharp melting points, and may cleave easily to give new plane surfaces. Crystals also interact with x-rays to produce well-defined diffraction patterns. Such properties lead us to believe that crystals are composed of regular, repeating arrangements of atoms. The film raises the question of how we actually discover these arrangements. Experiments are then performed in a ripple tank on an unknown crystalline array so that the student sees the principles and measurements by which actual crystal structures are determined.

#4139 Black & white

SHAPES & POLARITIES OF MOLECULES

Collaborator: Professor David Dows, University of Southern California, Los Angeles.

Observations of electrical effects, including deflections of a stream of falling liquid by an electrically charged rod, lead to the concept of molecular polarity. Covalent substances give two types of results: some show very marked interactions with electric charges, while others give little effect. A model, or concept, is developed, based on polar and nonpolar molecules. Considerations of bond polarity and molecular symmetry correlate the electrical effects and their change as temperature is varied. The molecular dipole model is extended to explain differences in solubility, conductivity and chemical reactivity.

#4154 In color

MECHANISM OF AN ORGANIC REACTION

Collaborator: Professor Henry Rapoport, University of California, Berkeley.

A thorough study of the hydrolysis of an organic ester shows that the discovery of a reaction mechanism—the actual steps by which a reaction proceeds—includes a determination of: (1) The chemical equation, (2) The structures of the reactants and the products, (3) The fate of each atom of the reactants, and (4) The structures of the intermediate molecules. The concepts of bond polarity and the effect of varying structures of one reactant also provide valuable hints. The use of ^{18}O and its detection on the mass spectrometer provide critical experimental data for the particular mechanism of ester hydrolysis.

#4166 In color

BROMINE CHEMISTRY

Collaborator: Dr. J. Leland Hollenberg, CHEM Study Staff.

Experiments show the great reactivity of bromine with metals and non-metals, giving products readily soluble in water. After exploring the chemical equilibrium of an aqueous solution, a procedure is developed for the extraction of bromine from a dilute sodium bromide solution such as sea water. The essential steps are: oxidation by chlorine to elementary bromine, concentration in the form of aqueous hydrogen bromide, and reoxidation followed by steaming-out the bromine. The same principles which have been demonstrated in the laboratory are then shown in operation in a commercial plant which annually extracts millions of pounds of bromine from sea water.

#4169 In color

VANADIUM, A TRANSITION ELEMENT

Collaborator: Professor Robert Brasted, Professor of Chemistry, University of Minnesota, Minneapolis.

Vanadium is studied as a typical transition element. The different oxidation states of vanadium and their colors are observed and then identified by means of a quantitative titration of vanadium (II) solution with cerium (IV) solution. The oxidation states and the observed colors are correlated with the electronic structures using an orbital board. The formation of complex ions containing vanadium in different oxidation states is demonstrated. The variations in properties in terms of ion size and charge density are discussed.

#4172 In color

APPENDIX D. BIOLOGICAL SCIENCES CURRICULUM STUDY

1. High School Biology: Green Version—The Laboratory (1963 Edition)

CONTENTS

CHAPTER 1

Basic	Ex 1.1	Observing Living Things
Basic	Ex 1.2	An Experiment: The Germination of seeds
Basic	Ex 1.3	Interrelationships of Producers and Consumers
Basic	Ex 1.4	Use of the Microscope: Introduction
Basic	Ex 1.5	Use of the Microscope: Biological Materials
Optional	Ex 1.6	Use of the Stereoscopic Microscope

CHAPTER 2

Basic	Ex 2.1	Population Growth: A Model
Basic	Ex 2.2	Study of a Yeast Population
Basic	Ex 2.3	Factors Limiting Populations
Optional	Ex 2.4	Effect of an Abiotic Environmental Factor on a Population

CHAPTER 3

Basic	Ex 3.1	The Study of a Biotic Community
Optional	Ex 3.2	Competition Between Two Species of Plants
Highly Rec.	Ex 3.3	A Comparative Study of Habitats

CHAPTER 4

Basic	Ex 4.1	Structural Characteristics in the Classification of Animals
Basic	Ex 4.2	The Levels of Classification
Highly Rec.	Ex 4.3	A Dichotomous Key for Identification of Insects
Highly Rec.	Ex 4.4	Diversity in the Animal Kingdom: A Comparative Study

CHAPTER 5

Basic	Ex 5.1	Diversity in the Plant Kingdom
Basic	Ex 5.2	Diversity in the Angiosperms

CHAPTER 6

Basic	Ex 6.1	A Garden of "Microorganisms"
Basic	Ex 6.2	Experiments on Spontaneous Generation
Highly Rec.	Ex 6.3	Microscopic Study of Bacteria

CHAPTER 7

Basic	Ex 7.1	Decomposing Action of Soil Microbes
Basic	Ex 7.2	Some Microbial Techniques
Basic	Ex 7.3	Investigating an Infectious Disease

Highly Rec.	Ex 7.4	Nodule-Forming Bacteria
Optional	Ex 7.5	Growing Soil Microbes by the "Mud Pie" Technique
Optional	Ex 7.6	Soil Nematodes
Optional	Ex 7.7	The Abundance of Air-Borne Microorganisms in Various School Environments

CHAPTER 8

Basic	Ex 8.1	Limiting Factors in Distribution
Basic	Ex 8.2	Temperature, Rainfall and Biome Distribution
Highly Rec.	Ex 8.3	Effects of Fire on Biomes

CHAPTER 9

Basic		A Field and Laboratory Study of a Pond Community
Highly Rec.		Making and Studying Artificial Pond Ecosystems
Highly Rec.		Effects of Salinity
Highly Rec.		Collection and Identification of Marine Plankton or Collection and Identification of Marine Organisms
Highly Rec.		Salinity and The Brine Shrimp

CHAPTER 10

No Laboratory Exercises

CHAPTER 11

Highly Rec.		Barriers and Dispersal

CHAPTER 12

Basic		Organization and Activities of Protoplasm
Basic		Diversity of Cells
Basic		Diffusion through a Membrane
Basic		Mitosis
Highly Rec.		Detection of Organic Substances
Highly Rec.		A Study of Enzyme Action

CHAPTER 13

Basic		Extraction and Separation of Pigments from a Green Leaf
Highly Rec.		Food Reserves in Plants
Basic		Loss of Water By Plants
Highly Rec.		Transport of Phosphates in Plants
Basic		Action of a Plant Enzyme
Highly Rec.		Plant Hormones and Mechanisms of Phototropisms
Optional		Algae and Fungi

CHAPTER 14

Basic		Anatomical Structures and Physiological Processes
Highly Rec.		Maintaining Water Balance
Basic		Muscles and Locomotion—Muscles at Work

BIOLOGY (GREEN VERSION)

Highly Rec.	Capillary Circulation
Optional	Testing Foods for Vitamin C
Highly Rec.	Hydrolysis of Fats
Basic	Chemoreceptors in Man
Highly Rec.	The Amount of Carbon Dioxide Produced by Man
Optional	Relationship of Radiation Injury to Metabolic Rate
CHAPTER 15	
Basic	Meiosis
Basic	Development of Chick Embryo or Frog (as alternative)
Highly Rec.	Regeneration in Planaria or Plants (as alternative)
Optional	Growth Curve
Highly Rec.	Reproduction and Development in Flowering Plants
Optional	Reproduction in Ferns
Optional	Reproduction and Life History of Pine
Optional	The Effects of X-Radiation on Seeds
CHAPTER 16	
Basic	Probability
Basic	Heredity and Environment
Highly Rec.	How Genes Act
Basic	Distinguishing Male and Female Drosophila
Basic	A Cross Between Two Genetic Strains of Drosophila
Highly Rec.	A Test Cross
Highly Rec.	Independent Inheritance
Optional	Linkage and Crossing-Over
Optional	Sex linked Inheritance
Basic	Human Inheritance
Highly Rec.	Genetic Differences in Peas
Optional	Neurospora—Detecting Nutritionally Deficient Strains
Optional	Neurospora—The Procedure for Crossing Strains
CHAPTER 17	
Basic	A Populations Genetics Study
Basic	Populations and Evolution
Highly Rec.	Sickle Cells and Evolution
Highly Rec.	Biological Distance
Highly Rec.	Effect of Population Size
Optional	Induction of Polyploidy
Optional	Adaptive Radiation and Convergent Evolution
Optional	Competition in a Laboratory Environment
CHAPTER 18	
Highly Rec.	Photoperiod and Plant Behavior
Basic	Introduction to Animal Behavior
Highly Rec.	Light Intensity and Fruit Fly Movement
Optional	Paramecia and Electrical Stimulation
Optional	Social Relationships in Fish
Highly Rec.	Tropisms

BIOLOGY (GREEN VERSION)

CHAPTER 19

Basic	Human Peculiarities
Optional	Skulls of Man and Other Primates
Basic	Blood Types

CHAPTER 20

No Laboratory Exercises

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BSCS (671)
3/12/63

2. High School Biology: Yellow Version—The Laboratory
(1963 Edition)

CONTENTS

BIOLOGY (YELLOW VERSION)

Basic	Ex 13-1	(old 111B)	Green Algae, Simple and Complex
Basic	Ex 14-1	(old 112B)	Alternation of Generations
Supp.	Ex 14-2	(old 113)	A Primitive Vascular Plant
Basic	Ex 14-3	(old 114)	The Importance of Seeds
Basic	Ex 15-1	(old 84)	The Extraction and Separation of Pigments in a Green Leaf
Basic	Ex 15-2	(old 86)	Chlorophyll and Photosynthesis
Supp.	Ex 15-3	(old 88)	Light—A Factor in Carbohydrate Synthesis
Supp.	Ex 15-4	(old 91)	The Stoma—A Gateway Into The Leaf
Supp.	Ex 15-5	(old 92)	The Leaf—A Photosynthetic Organ
Supp.	Ex 16-1	(old 93)	The Stem—Structure and Function
Supp.	Ex 16-2	(old 95)	The Root—An Aid to Plant Nutrition
Basic	Ex 16-3	(old 98)	Transpiration in Plants
Supp.	Ex 17-1	(old 99B)	The Flower
Supp.	Ex 17-2	(old 116)	A Simple Key to Study Differences in Flowering Plants
Basic	Ex 17-3	(old 100)	Seeds and How they Grow
Basic	Ex 17-4	(old 105B)	Plant Reactions to Environment
Supp.	Ex 17-5	(old 107)	The Regulation of Growth in Plants

SECTION C. Total 20 (9 Basic, 11 Supplementary)

SECTION D

Basic	Ex 19-1	(old 52)	Correlation of Structure and Function in Paramecium
Basic	Ex 19-2	(old 53)	Movement of Paramecium
Basic	Ex 19-3	(old 54)	Ingestion of Food and Digestion in Paramecium
Basic	Ex 19-4	(old 55)	A Study of Contractile Vacuoles in Paramecium
Basic	Ex 19-5	(old 56)	Behavior in Paramecium
Basic	Ex 19-6	(old 57)	Reproduction in Paramecium
Supp.	Ex 20-1	(old 60)	Worm Way of Life
Supp.	Ex 20-2	(old 61)	Animals with Jointed Appendages
Supp.	Ex 20-3	(old 64)	Form and Function in the Frog
Basic	Ex 20-4	(old 63A)	Principles of Animal Classification
Supp.	Ex 21-1	(67 Blue)	Digestion of Foodstuffs
Supp.	Ex 22-1	(old 68)	The Living Invertebrate Heart
Supp.	Ex 22-2	(old 67)	Capillary Circulation
Supp.	Ex 23-1	(old 73)	The Production of Carbon Dioxide in Human Beings
Supp.	Ex 24-1	(old 76)	Homeostasis and The Human Kidney
Basic	Ex 25-1	(old 77)	Introduction to Animal Behavior
Supp.	Ex 26-1	(old 79)	Regulation of Contraction in Cardiac Muscle (heart) and Smooth Muscle (stomach)
Basic	Ex 27-1	(old 117)	Effects of the Reproductive Hormones on Secondary Sex Characteristics
Basic	Ex 28-1	(old 118)	Reproduction and Development of the Frog
Supp.	Ex 28-2	(old 119)	Chick Development
Supp.	Ex 29-1	(old 120)	Regeneration

SECTION D. Total 21. (10 Basic, 11 Supplementary)

SECTION E

Basic	Ex 30-1	(old 123)	Drosophila Technique
Basic	Ex 30-2	(old 126)	Randomness, Chance and Probability

Basic	Ex 30-3	(old 124)	The Inheritance of One-Factor Differences
Supp.	Ex 30-4	(old 125)	Independent Differences
Supp.	Ex 31-1	(old 127)	Linkage and Crossing-Over
Supp.	Ex 31-2	(old 128)	Sex-Linked Inheritance
Supp.	Ex 32-1	(old 131)	Genetic Differences in Peas
Supp.	Ex 32-2	(old 132)	Nutritional Mutants in Neurospora
Basic	Ex 33-1	(old 133)	A Population Genetics Study
Basic	Ex 33-2	(old 129)	Human Inheritance
Basic	Ex 33-3	(old 130)	Heredity and Environment

SECTION E. Total 11. (6 Basic, 5 Supplementary)

SECTION F

Supp.	Ex 34-1	(old 135)	Effect of Selection Pressure on Allele Frequencies
Basic	Ex 34-2	(old 136)	Sickle Cells and Selection
Supp.	Ex 35-1	(old green 16.3)	Biological Distance
Basic	Ex 36-1	(old green 16.2)	Adaptive Radiation and Convergent Evolution Among Mammals
Supp.	Ex 36-2	(new)	A Study of Fossil Plants

SECTION F. Total 5. (2 Basic, 3 Supplementary)

SECTION G

Supp.	Ex 39-1	(2.2 green)	A Terrestrial Community
Supp.	Ex 39-2	(6.4 green)	Ecological Succession

SECTION G. Total 2. (2 Supplementary)

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BSCS (671)
3/12/63

3. High School Biology: Blue Version--The Laboratory

(1963 Edition)

CONTENTS

The following is a list of laboratory exercises which appeared in the experimental revised edition and will be used, in modified form, in the new laboratory manual.

BIOLOGY (BLUE VERSION)

NOTE:—

There will be some laboratory studies regarding Drosophila and genetics similar to those in the old book under Exercises 35, 36, and 37.

NOTICE:—

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3/12/63

APPENDIX E

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________________ *Green Version—High School Biology*. Chicago: Rand McNally & Company.

________________ *Yellow Version—Biological Science: An Inquiry Into Life*. New York: Harcourt, Brace & World Company.

________________ Laboratory Blocks—*Plant Growth and Development; Animal Growth and Development; Microbes: Their Growth, Nutrition and Interaction;* and *Interdependence of Structure and Function*. And *Equipment and Techniques for the Biology Teaching Laboratory*. Boston: D. C. Heath and Company.

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Catalogues and Publications of Continuing Interest

BSCS *Newsletters* and other announcements may be obtained directly from BSCS, University of Colorado at Boulder.

CHEM Study, *Catalogue of Films*. Available from Modern Learning Aids, 3 East 54 St., New York 22, New York.

National Academy of Sciences—National Research Council, *Publications*. Washington, D. C.; NAS-NRC, Fall, 1958.

National Science Foundation, *Science Course Improvement Projects*, Courses, Written Materials, Films, and Studies Supported by the National Science Foundation. NSF Pub. 62-38, Oct. 1962.

Physical Science Study Committee, *Catalogue of PSSC Films*. Available from Modern Learning Aids, 3 East 54 St., New York 22, New York.

Science Education News. Published quarterly by the American Association for the Advancement of Science, 1515 Massachusetts Ave., Washington 5, D. C.

The Science Teacher. Journal of the National Science Teachers Association. Published monthly except January, June, July and August. 1201 16th St., N.W., Washington 6, D. C.